0183

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

EVALUATION OF THE CINCINNATI MILACRON T^3 ROBOT FOR SHIPBUILDING WELDING

U.S. DEPARTMENT OF TRANSPORTATION

MARITIME ADMINISTRATION

IN COOPERATION WITH

NEWPORT NEWS SHIPBUILDING

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CINCINNATI MILACRON T-3 ROBOT

FOREWORD

The purpose of this report is to present the results of one of the research and development programs which was initiated by the members of the Ship Production Committee of the Society of Naval Architects and Marine Engineers (SNAME], and financed largely by government funds through a cost-sharing contract between the U. S. Maritime Administration and Newport News Shipbuilding. The effort of this project was directed to the selection and testing of a robotic arc welding system for use in U.S. shipyards.

Mr. M. I. Tanner andMr. B. C. Howser, of Newport News Shipbuilding, were Program Managers. Mr. J. B. Acton and Mr. J. P. Maciel, of Todd Pacific Shipyards Corp. - Los Angeles Division (TPLA), were Project Managers. Messrs. J. B. Acton, D. A. Lang and R. K. Nordeen, of TPLA, were the Principal Investigators.

Special acknowledgement is extended to the members of Welding Panel SP-7 of the SNAME Ship Production Committee, who served as technical advisors in the preparation of inquiries and evaluation of subcontract proposals, and to Newport News Mr. M. I. Tanner forsaking possible the report compilation.

FINAL REPORT

CINCINNATI MILACRON T-3 ROBOT
Project Task No. 7-2

January 1984

BY:

TODD PACIFIC SHIPYARDS CORPORATION

Los Angeles Division

710 Front Street

San Pedro, CA 90733

UNDER:

MARAD CONTRACT NO.: MA-80-SAC-01041

Project Managers:

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Investigators:

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D. A. Lang, Jr.
R. K. Nordeen

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1. Summary

1.1 Purpose

The purpose of this report is to aid in the formulation of laboratory , programs reflecting customer's needs, and effectively communicate the considerations/issues to appropriate levels of management. This report documents the rationale for strong/weak points, deficiency notices, and offers what is believed to be an improvement in reference to:

- ° Operational performance of the robot and its work station (compliance with functional requirements).

- ° Degree of usefulness of the arc welding robot system in the shipbuilding industry.

1.2 Conclusion

Utilization of the robot to weld fairly complex aluminum and steel subassemblies confirmed that a programmable, automated machine can be taught to manipulate the tool attached to it and to consistently, accurately, and fast perform the process as defined. However, it was also determined that close tolerance fit-up and positioning is necessary with existing technology. Teaching time was identified as the most significant factor limiting the productivity of the robot in small batch manufacturing operations.

Determining the degree of usefulness of arc-welding robot systems in the shipbuilding industry is an ongoing task. Specifications for their purchase, implementation, maintenance and standardization should be developed as robotic technology improves.

1.3 Recommendation

Results of Todd's evaluation established a need for developing faster operator-friendly teaching devices and a dependable vision seam tracker, which would greatly decrease the programming time, the program modifying time and the dry run time, thus increasing the efficiency of the robot and safety of it's operators.

2. Background

2.1 Objective

Welding has been identified as one of the key cost drivers for the shipbuilding industry. In order to reduce fabrication cost by improved productivity and improved quality of work, it was decided to use Flexible Automation in the area of welding.

2.2 Approach

An inhouse assessment was made of physical characteristics of parts required by past contracts. Based on this study, the Cincinnati Milacron T3 robot was selected and delivered to the shipyard. After obtaining the operation and maintenance documentation, an operator was carefully selected and sent along with maintenance personnel for factory training. The robot and associated equipment became operational in October 1981.

2.3 Interim Report - This report embodies the November 15, 1982 Interim report with additional data and information. Much of the initial information has been updated although there are sections of this report which were not changed from the Interim Report.

3. Work Station

3.1 General

This section briefly describes the work station consisting of the main equipment:

- Robot
- Robot Control Unit
- Hydraulic Unit
- Welding Unit

The arcwelding robot and associated equipment occupies an area of approximately 35′ x 26′ in the Plate Shop; Figures l and 2 represent layouts of the original installation and final installation, respectively. The work stations were designed in accordance with all applicable local, state and federal regulations in addition to two prime objectives:

- Safety of personnel and equipment
- Efficient use of the robot's working envelope

3.2 Robot

The robot and work cell are shown Figures 3 and 4, respectively.

3.2.1 Specification

The robot used in this evaluation is a Cincinnati Milacron T3 industrial robot. See Exhibit 1. Pertinent features include:

- 6-axis jointed arm construction
- Independent electro-hydraulic servo-controlled system for each axis
- Resolver and tachometer position feedback device for each axis
- Repeatability to any programmed point ± 0.025 in.
- Maximum horizontal sweep 240 degrees
- Maximum horizontal reach 97″ end effecter
- Minimum to maximum reach, floor to ceiling 0″-154″

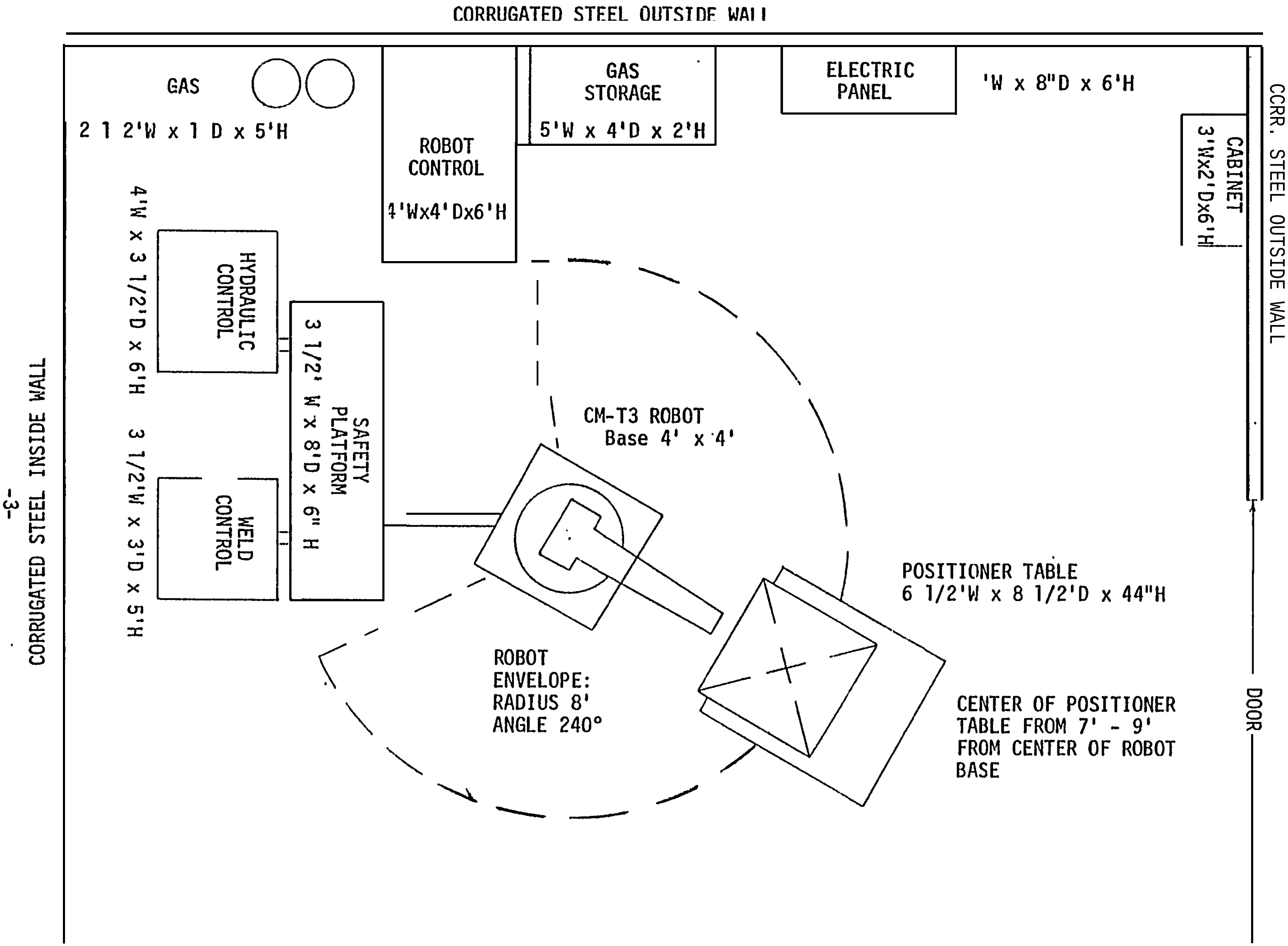
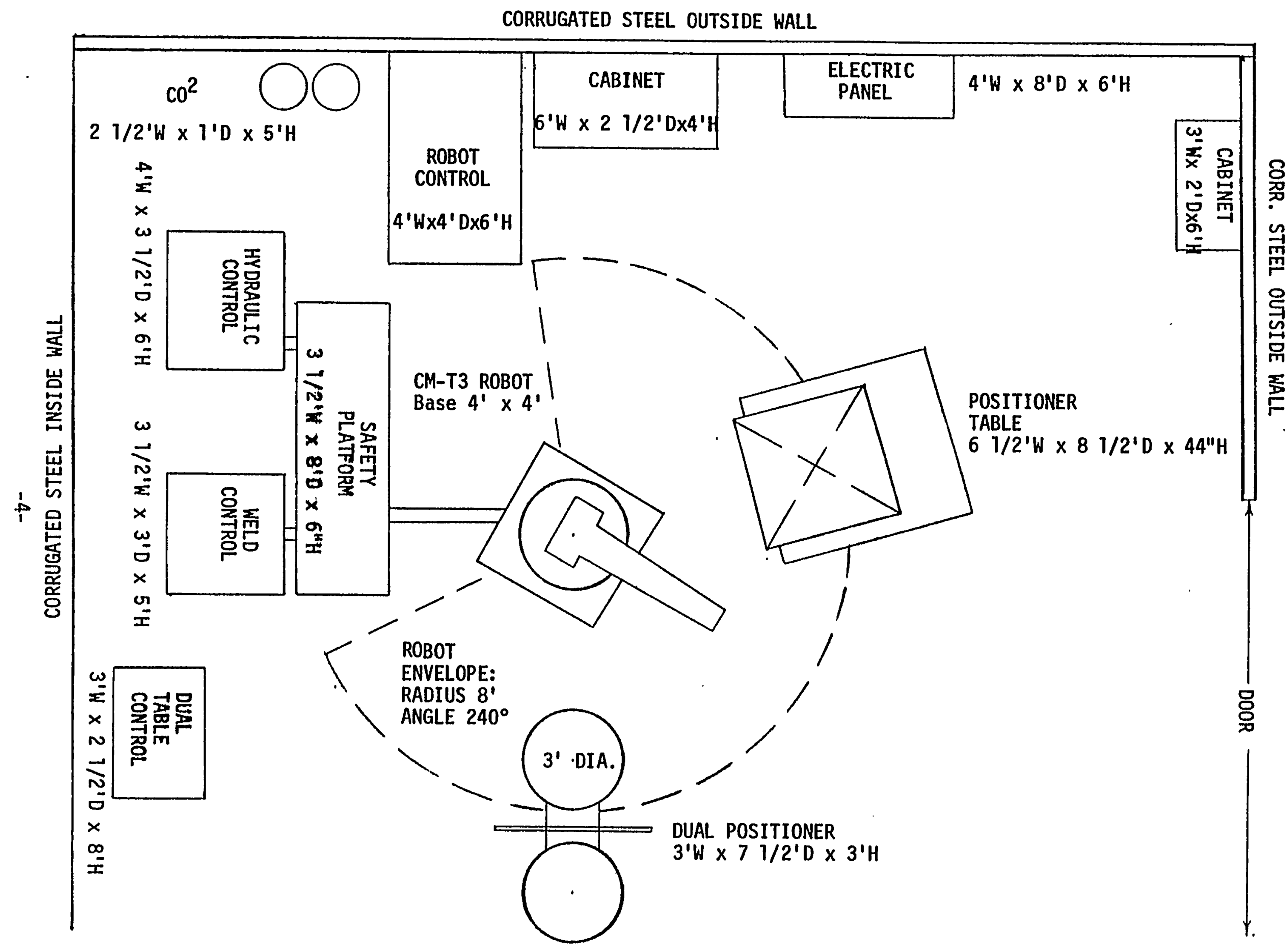

CORRUGATED STEEL OUTSIDE WALL
GAS
2 1 2'W x 1 D x 5'H
ROBOT CONTROL
4'Wx4'Dx6'H
GAS STORAGE
5'W x 4'D x 2'H
ELECTRIC PANEL
'W x 8"D x 6'H
CABINET
3'Wx2'Dx6'H
CCRR. STEEL OUTSIDE WALL
HYDRAULIC CONTROL
4'W x 3 1/2'D x 6'H
SAFETY PLATFORM
3 1/2' W x 8'D x 6" H
WELD CONTROL
3 1/2'W x 3'D x 5'H
CORRUGATED STEEL INSIDE WALL
CM-T3 ROBOT
Base 4' x 4'
POSITIONER TABLE
6 1/2'W x 8 1/2'D x 44"H
ROBOT ENVELOPE:
RADIUS 8'
ANGLE 240°
CENTER OF POSITIONER TABLE FROM 7' - 9' FROM CENTER OF ROBOT BASE
DOOR

FIGURE 1


CORRUGATED STEEL OUTSIDE WALL
CO2
2 1/2'W x 1'D x 5'H
ROBOT CONTROL
4'Wx4'Dx6'H
CABINET
6'W x 2 1/2'Dx4'H
ELECTRIC PANEL
4'W x 8'D x 6'H
CABINET
3'Wx 2'Dx6'H
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CM-T3 ROBOT
Base 4' x 4'
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6 1/2'W x 8 1/2'D x 44"H
CORRUGATED STEEL INSIDE WALL
3 1/2'W x 3'D x 5'H
WELD CONTROL
ROBOT ENVELOPE:
RADIUS 8'
ANGLE 240°
DOOR
3'W x 2 1/2'D x 8'H
DUAL TABLE CONTROL
3' DIA.
DUAL POSITIONER
3'W x 7 1/2'D x 3'H

FIGURE 2

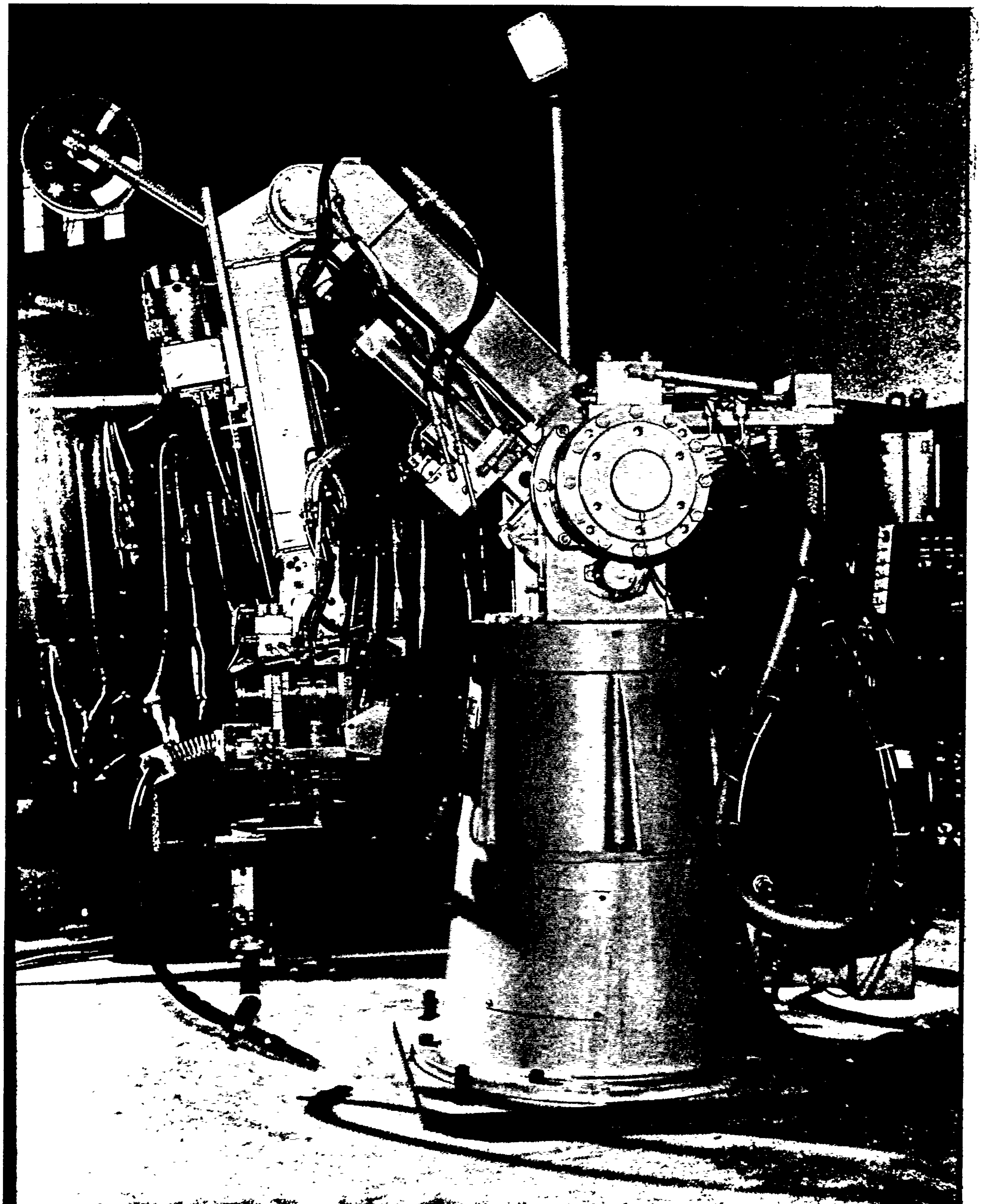


FIGURE 3

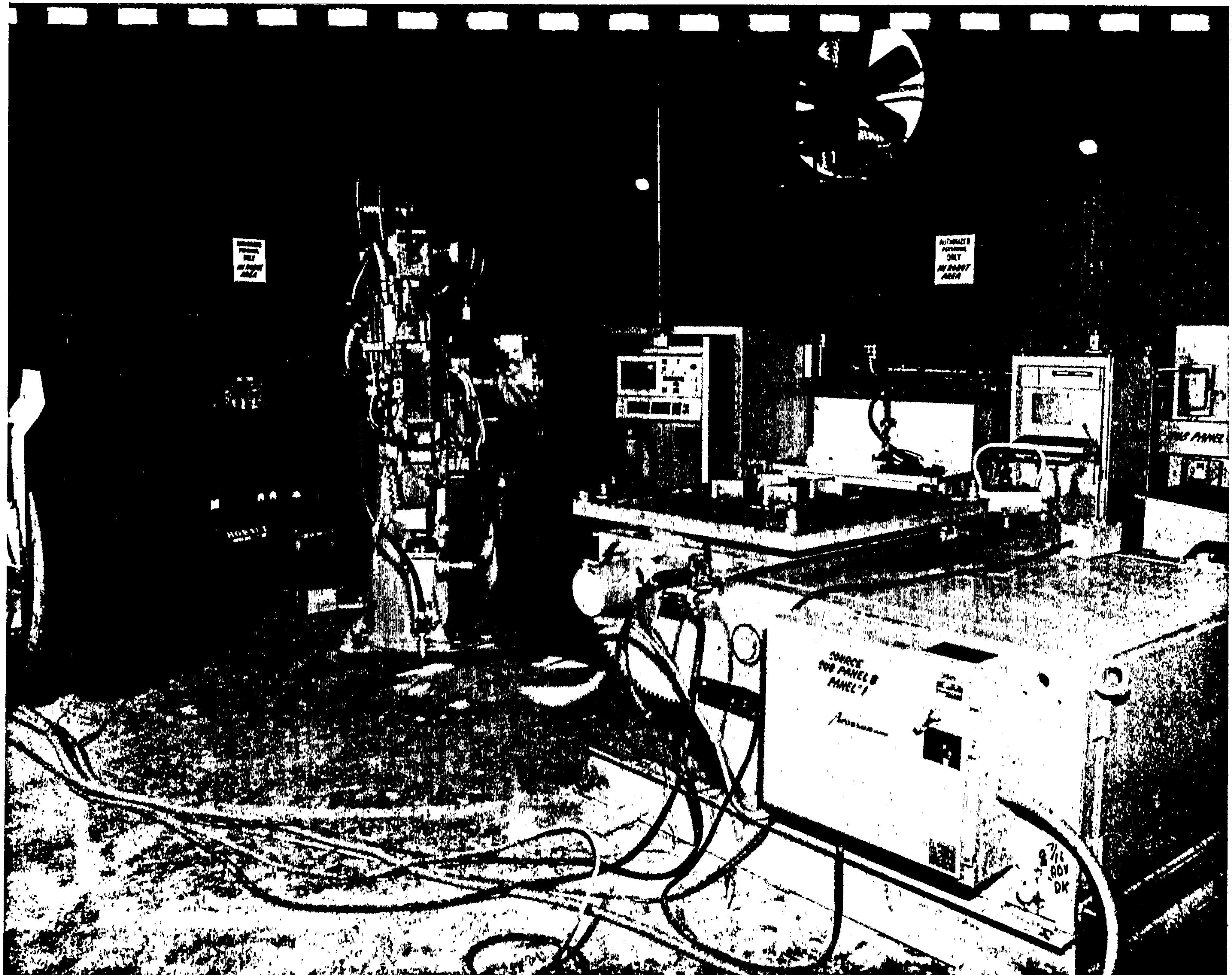


FIGURE 4

3.2.1 Specification (cent'c!)

- Maximum velocitv 900 1PM
- Wrist motions -"pitch 180 degrees
  roll 24C degrees
  yaw 180 degrees
- Environmental temperature range 40-120 degrees Fahrenheit

3.2.2 Evaluation

3.2.2.1 Performance

The robot performed well in all aspects of the operation; in some cases exceeded the specifications. The accuracy and motion is suitable for most welding applications. The weld quality is superior to that produced by a human.

3.2.2.2 Maintenance and Service

The robot has logged approximately 2700 hours of operation during the evaluation period with few breakdowns or mechanical malfunctions. Service was usually performed by trained Todd personnel. The availability and assistance of Cincinnati Milacron servfce personnel, when needed, was excellent.

3.2.2.3 Recommendation

The welding application does not require that the robot have a significant lifting capacity; a characteristic of hydraulic robots. It is recommended that electric robots be investigated for the welding application.

3.3 Robot Control Console

3.3.1 Location

Efficient and safe operation of the equipment is sensitive to the location of the robot control unit. The equipment currently being used required that variable information about each point in a program be input at the control unit. This means that after leading the robot to a desired location, (usually done in the vicinity of the part via the portable "button box" control), the operator must proceed to the control console to input instructions about the point. Consequently, three factors are important in locating this unit:

- It should be located as close to the prospective work areas as possible
- The path between work area and control unit should be unobstructed

3.3.1 Location (cent'd)

° When working at the console, the operator should be out of the robot's envelope and/or the operator should have at least peripheral sight of the robot arm

The first two considerations are important because of the significant amount of time spent programming in a small batch manufacturing application. The third consideration is necessitated by-operator and equipment safety.

3.3.2 Specification

The robot control system used was Cinc0innax" MilIacron s Acramatic Computer Control. See Figure 5. Pertinent features Include:

" Infinitely variable 6-axis positioning
" Controlled straight-line motion between programmed points (point-to-point)
° Alpha-numeric keyboard for program data entry
° Large character CRT for functional data display and diagnostic messages
° Hand-held teach unit for manipulating end effecter through desired motions

3.3.3 Control and Teaching Functions

° Coordinated straight-line motion with automatic acceleration and deceleration between consecutive programmed points
° 1750-data point storage capacity
° Programmable path velocities
° Choice of cylindrical , rectilinear, or hand-coordinated motions during teaching
Movements during teaching about tool center point
Three selectable tool dimensions for different tool center points locations
° Full program editing capability
° Capability of creating a mirror image of previously taught program
° Modify capabilities of all coordinate values, function, velocity, and tool dimension
° Built-in malfunction diagnostics incorporating automatic machine shutdown

3.3.4 Evaluation

3.3.4.1 Performance

The CM Acramatic computer control hardware performed to its specifications throughout the evaluation. The unit was not significantly affected by the environment and has operated with only a few malfunctions.

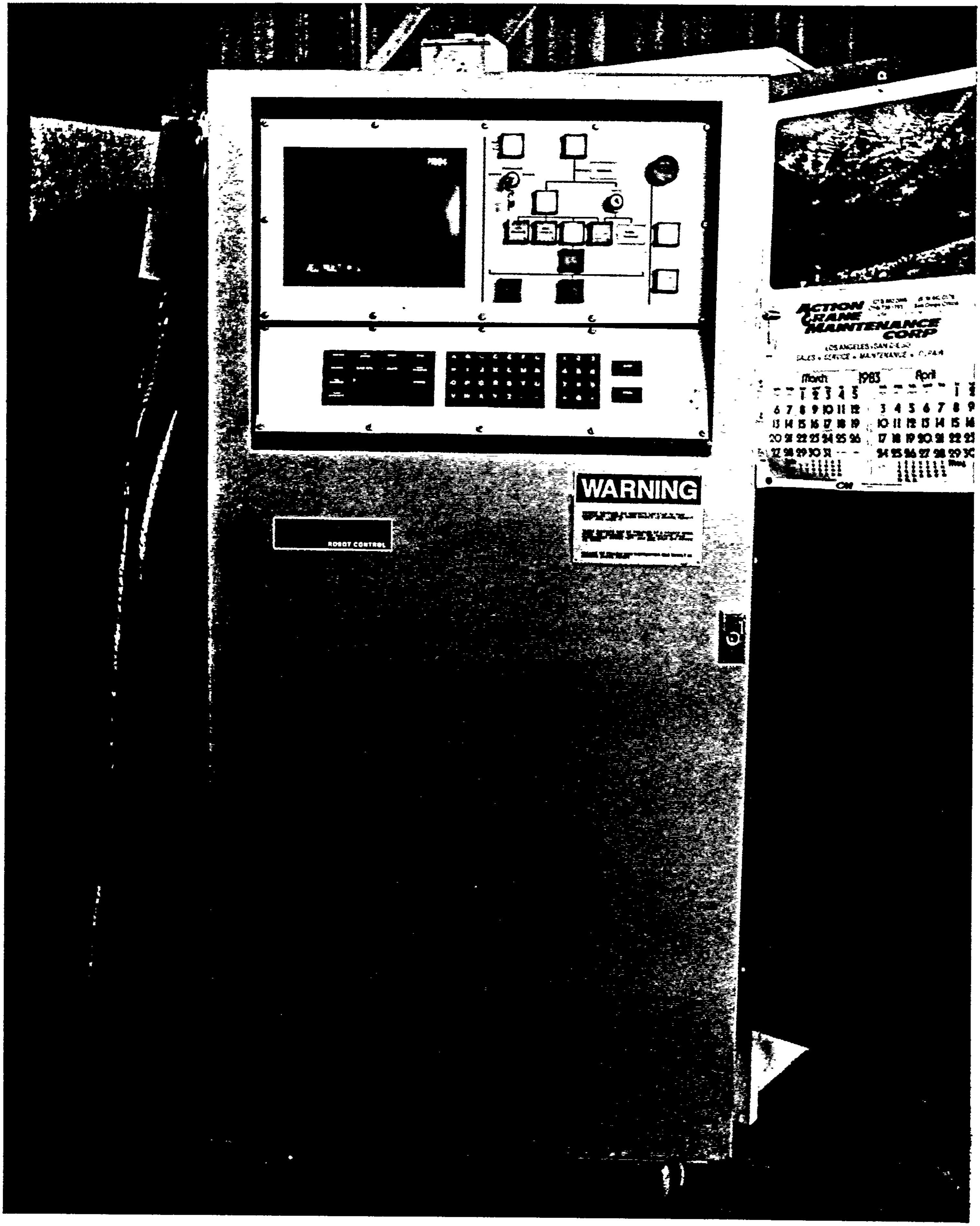

WARNING
ROBOT CONTROL
ACTION CRANE MAINTENANCE CORP
March 1983 April

FIGURE 5

3.3.4.2 Maintenance and Service

The unit was serviced by trained Todd personnel or Cincinnati Milacron service personnel.

3.3.4.3 Recommendation

The most significant shortcoming of the control system is the. accompanying software package. The system is functionally sound in that it provides for all the variables and control commands necessary to the welding application; but, it is too bulky and time-consuming a system to adequately meet the needs of the small batch manufacturing industry. Recommend to continue defining the control operations that are limiting the success of the present system and recommend developing new systems;

3.4 Hydraulic Power Supply

3.4.1 Specification

The robot is powered by a hydraulic power supply (See Figure 6), the following are a few of its specifications:

Operating pressure 2250 psi
Drive motor 25 HP, 1800 RPM
° Power requirements 230 or 460 volts, 3 phase, 60 HZ

3.4.2 Evaluation

3.4.2.1 Performance

The hydraulic unit performs to its specifications.

3.4.2.2 Maintenance and Service

The unit required only a limited amount of regular maintenance, in accordance with the operating manual.

3.4.2.3 Recommendation

The addition of a heating unit to assist in warming the hydraulic fluid. This would reduce the warm-up period and increase production.

3.5 Welding System

3.5.1 General

The welding system consisted of:

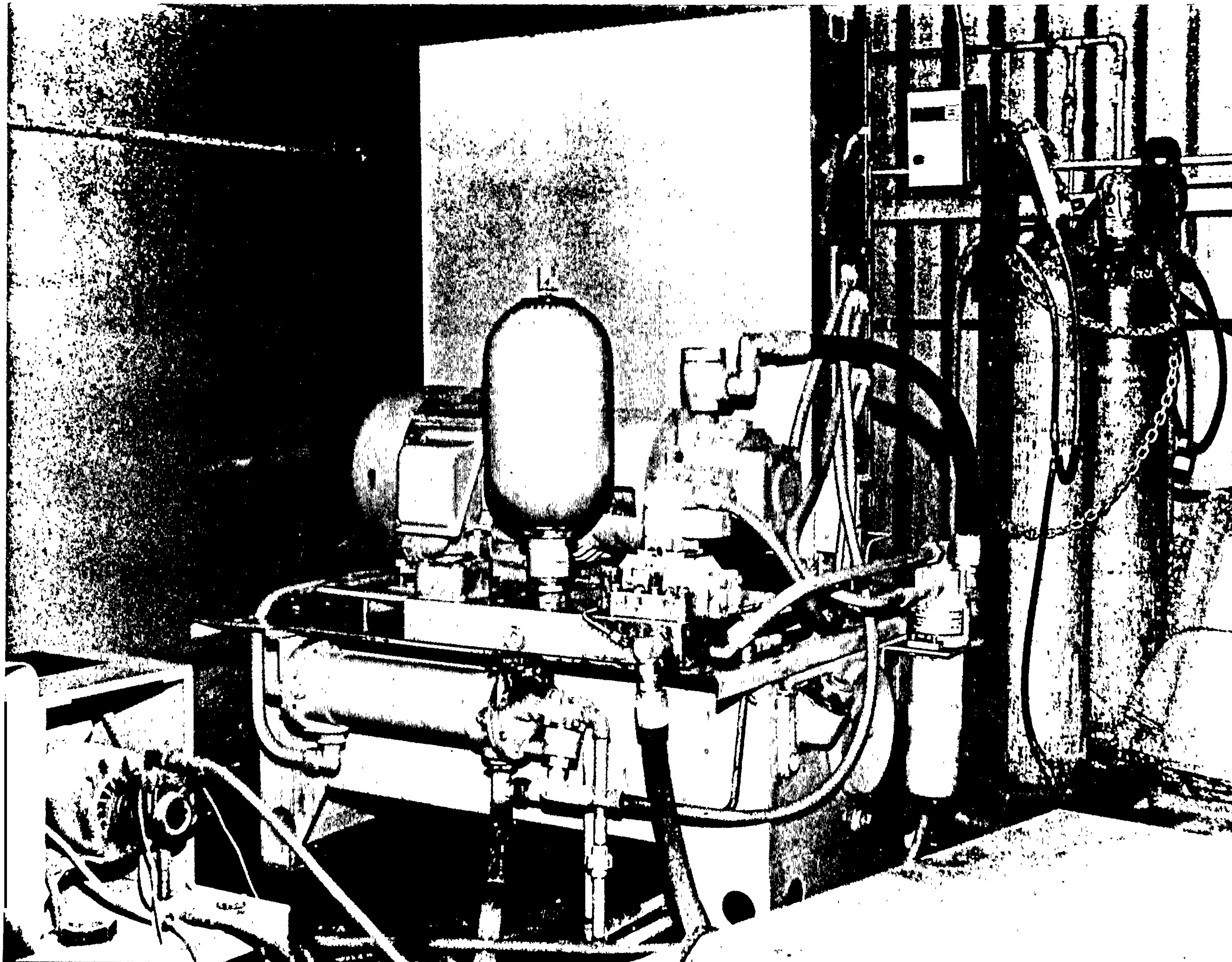


FIGURE 6

3.5.1 General (cont'd)

- Hobart - Robot Controlled Welding Control Panel
- Hobart - Constant Voltage Type Rectifier-Welding Nactiine
- Hobart - Wire Drive Feed Head
- Bernard - Stainless Steel Water Cooler

See Exhibits 2 to 6.

3.5.2 Evaluation

3.5.2.1 Performance

The welding system performs to its specifications.

3.5.2.2 Maintenance and Service

This system is maintained and serviced according to the factory instructions.

3.5.2.3. Recommendation- None

4. Support Equipment

4.1 General

The support equipment consists of:

- Positioners - Single &Dual
- Jigs and Fixtures
- Torch Assemblies and Torches

4.2 Positioners

4.2.1 Specification

The positioner selected initially was an Aronson two-axis positioner. Included for information is Fabrication Specialties dual positioner table, see Figure 7, 8 and 9. Pertinent features of both positioners is as follows:

Aronson (Model RAB60CS)

- 48" square table surface
  Adjustable securing clamps
- 360° rotation at 1 RPM
- 135° tilt at 1 RPM single speed
- 1800 lb. capacity
- Direction operation interface with robot control system

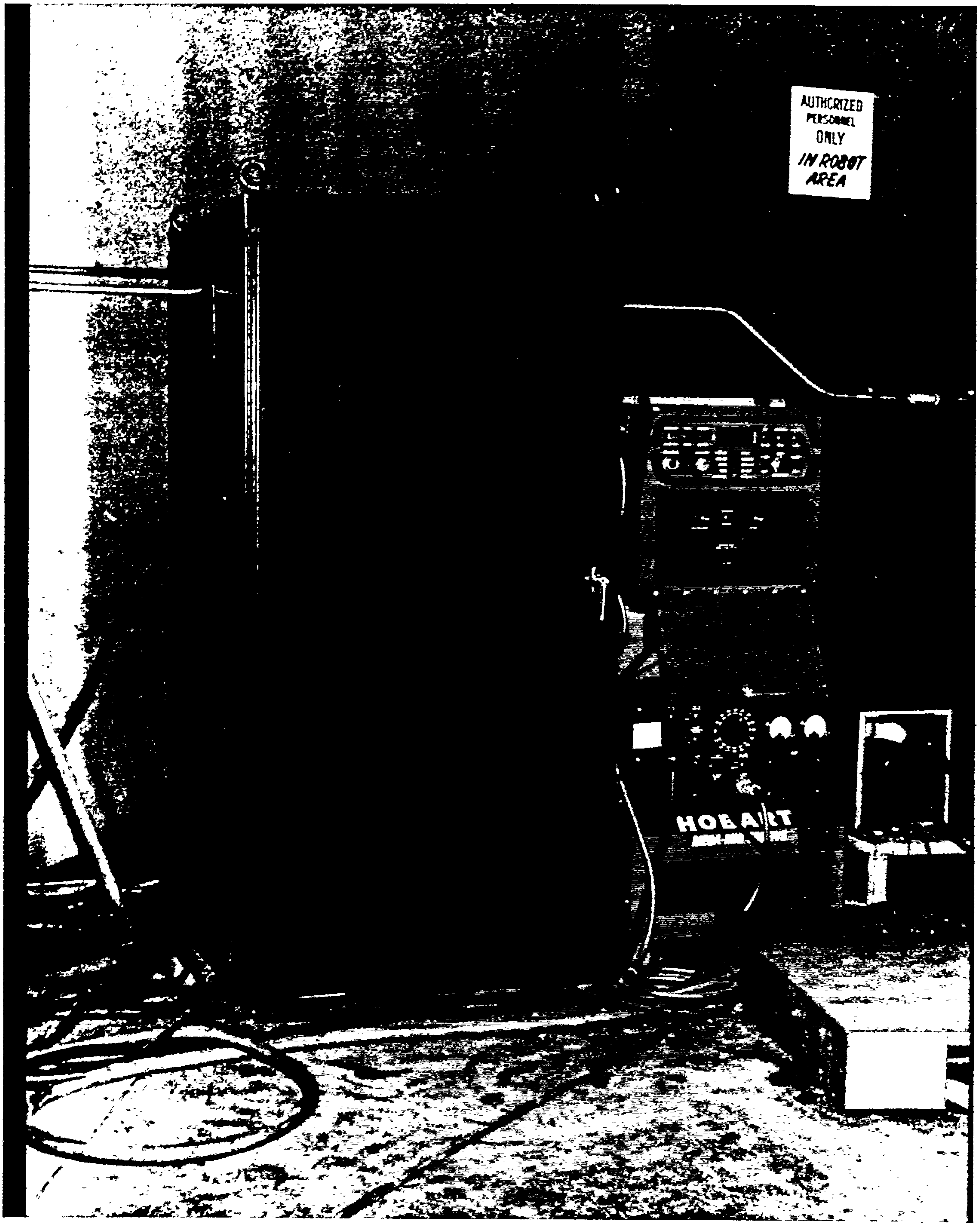


FIGURE 7

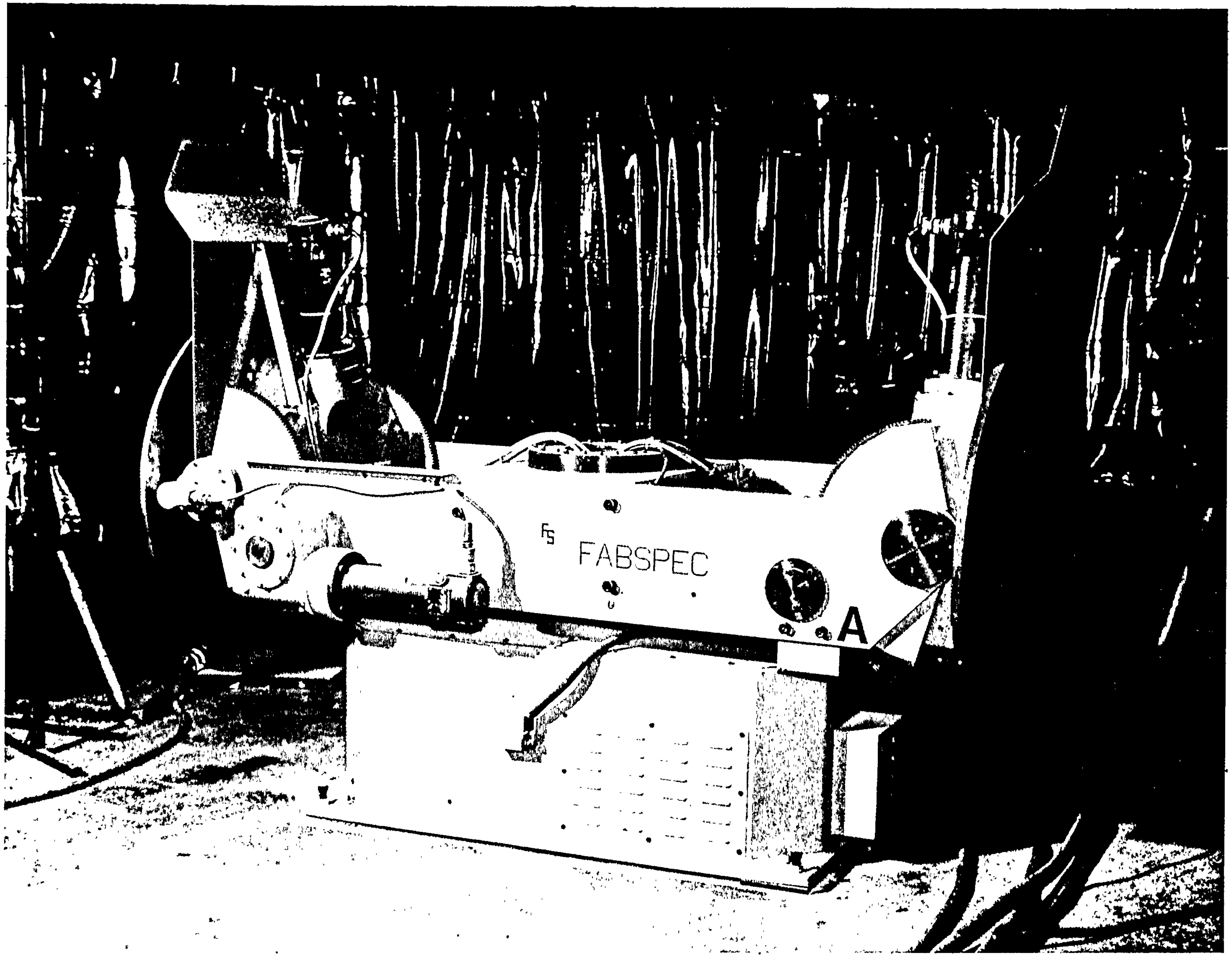


FIGURE 8

POSITIONER MOVEMENT

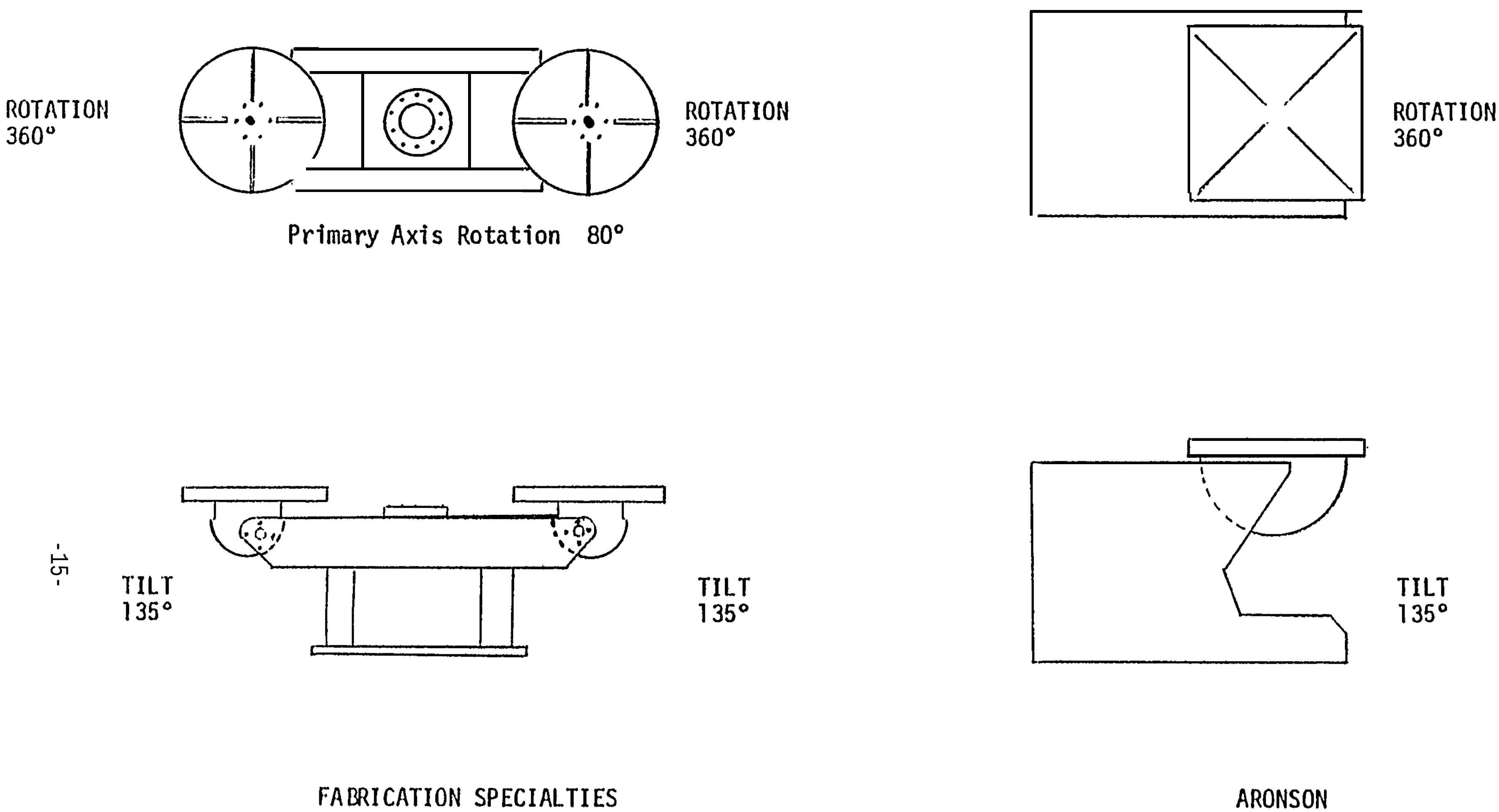


FIGURE 9

4.2.1 Specification (cont'd)

Fabrication Specialties (Model GD1000)

- Two 36" round table surfaces
- 360° rotation each table at 5 RPM
- 180° main sweep in 6.5 seconds
- 1000 lbs. capacity per table surface
- Direct operation interface with robot control system

4.2.2 Positioner Location

Location and orientation of the positioners are extremely important and can add considerable efficiency to the operation. The CM-T3 robot working envelope is of irregular shape, symmetrical only about the vertical plane (X-Z plane) passing through its center, see Exhibit lD. When only one positioner is used, the center line of the table is oriented along this plane of symmetry to maximize the reach of the robot arm to both sides of the table. Since the primary function of the two-axis positoner is to allow each joint of a part to be oriented in the ideal flat position, the center of the positioner is located so that when the table is in 45° tilt, the furthermost edge of the table is just within the working envelope.

The table is level with respect to the rubot's X-Y-Z translational (rectangular) movements. This coordinate system has proved the most effective in the teach mode (see Section 5). If the table is precisely positioned relative to the robot's translational movements, a part, properly oriented on the table will automatically have its right angle joints oriented along the robot lines of motion. As a result, teaching a segment requires a minimum amount of time and effort in leading the robot along the joint (ideally, one control command, in or out, left or right, up or down).

Implementation of two or more positioners, to the above orientation, will limit the size of the weldable parts as compared to having one positioner in the envelope. It might be necessary to utilize the working envelope according to size of parts, rather than ease of programming.

The advantage of using positioners in conjunction with the robot welder is that it allows each joint to be positioned in an ideal orientation for welding and allows access to all joints without having to move the workpiece. When utilizing multiple positioners, parts can be loaded and welded simultaneously.

4.2.3 Evaluation

4.2.3.1 Performance

The positioner tables have performed acceptably in most respects. The accuracy with which the positioners return to programmed positions is paramount in a robotic application. These units perform this function very well.

4.2.3.2 Maintenance and Service

These units were maintained and serviced in accordance with their respective factory instructions.

Due to control panel overheating problems, the dual table positioner required the addition of a Kool Tronic air-conditioning unit with the following specifications:

- Model KAC-6
- 6000 BTU
- Ambient temperatures from -50"F to 125°F max.

4.2.3.3 Recommendation

The Aronson (single table) motions are controlled by a single speed motor at a rate of one RPM, It is desirable to have variable speed control of the table movement. The Fabrication Specialties positioner has this variable speed which greatly enhances its performance. This speeds up the operation and increases the allowable size of circular parts that may be welded using the rotation of the table. The Aronson positioner has a single positioning surface, whereas the Fabrication Specialties positioner has two surfaces. With the single table positioner, the part loading and unloading process can be very unproductive. The dual table positioner's loading and unloading capabilities can greatly increase the operator efficiency (arc time).

Utilizing multiple positioners in the working envelope could possibly reduce the size of the parts capable of being welded; but, would increase the flexibility of the system. This possible trade off should be justified prior to installation of multiple positioners.

4.3 Jigs and Fixtures

4.3.1 General

The development of jigs and fixtures for part positioning, handling and securing will add to the productivity of the entire robot welding operation. Over the course of the evaluation, different clamps and fixtures were fabricated mostly to meet specific needs. Due to the variety of small batch ship parts and foundations, more universal positioning and securing fixtures were found to be the most desirable. These have to be accurate to insure repeatabi1ity, and fast to minimize the robot downtime while performing the positioning and securing function.

4.3.2 Positioner Table Surface Plates

A 3/8″ steel plate was cut to match the Aronson positioner table surface; key ways were machined diagonally to accommodate the tablets adjustable clamps, as shown on Exhibit 7B. The surface was indexed around the border of the plate with punch marks every 1/2″; each mark was nunbered. The plate was then secured to the positioner using the robot to align the X-Y index marks with the X-Y motion of the robot itself using two straight edges and the index marks. A part may be accurately located and subsequently relocated on the table surface with sufficient accuracy for the system; however, the time required for this operation is greater than desired. An improved table surface is currently at the conceptual design stage. This table surface features a more extensive key way system providing the ability to secure more than one small part at a time and accommodate positioning jigs; an advantage to both programming and welding efficiency. Aluminum parts are more subject to distortion during the weld process than steel parts. For this reason, a 3/8″ aluminum positioner table surface plate was made and installed on the Aronson positioner to allow aluminum parts *to* be tack welded directly to the positioner surface. This greatly reduced the weld heat distortion by providing adequate restraint. Upon weld completion, the tack welds are broken and the table surface prepared for the next part.

Fixturing was designed differently when utilizing the dual positioner. Jigs were made on 1/2″ thick plating which can be easily removed and replaced by another jig when welding a different part. See Exhibit 8.

4.3.3 Securing Clamps

Part securing clamps have been developed to meet the needs of specific parts and applications. The range of material thickness clamped to the table is from 3/16" to approximately 3". Small lightweight part clamping is easily accomplished with spring loaded/toggle clamps.

Large heavier parts are secured by clamps supplied with the positioner table. These clamps have a clamping range of O″

to approximately 4", and are tightened manually. See Figure 10.

4.3.4 Part Loading

Accurate relocation of similar parts on the positioner is essential to a robotic welding application. Presently, an electric two ton overhead crane is used to load parts and is found to be adequate.

4.3.5 Evaluation

4.3.5.1 Performance - Not applicable

4.3.5.2 Maintenance and Service - Not applicable

4.3.5.3 Recommendation

More research is needed in this area. Each particular application requires various different fixturing devices for jigs/clamps. Consideration should be given to the possible use of surface plates with fixturing devices on each plate and made to fit particular parts. These could be stored and scheduled to flow to the robot work station when that particular part needs welding.

4.4 Torch Assemblies and Torches

4.4.1 General

The welding torch assemblies and torches are critical elements of the robot welding system.

4.4.2 Torch Assemblies

The torch assembly consists of brackets and fixtures used to secure the welding torch onto the robot end effecter, in proper position. The standard "Home" (at rest) position of the CM-T3 arm allows a maximum tool dimension (distance from end effecter to torch tip) of 24 inches. This limited the length of the torch assembly. We have, in effect, extended this capability by lengthening the tool dimension 10 1/2". See Figure 11. Prior to returning to the standard "Home" position, the hinged portion of the bracket is released. This allows the arm to return to the standard "Home" position without damaging it.

Safety of the operator and equipment should be built into the torch assembly. This was initially accomplished by securing the torch to the mount with breakaway plastic straps. These provided some measure of safety but did not guarantee against injury or damage. The Binzel Corporation developed a safety

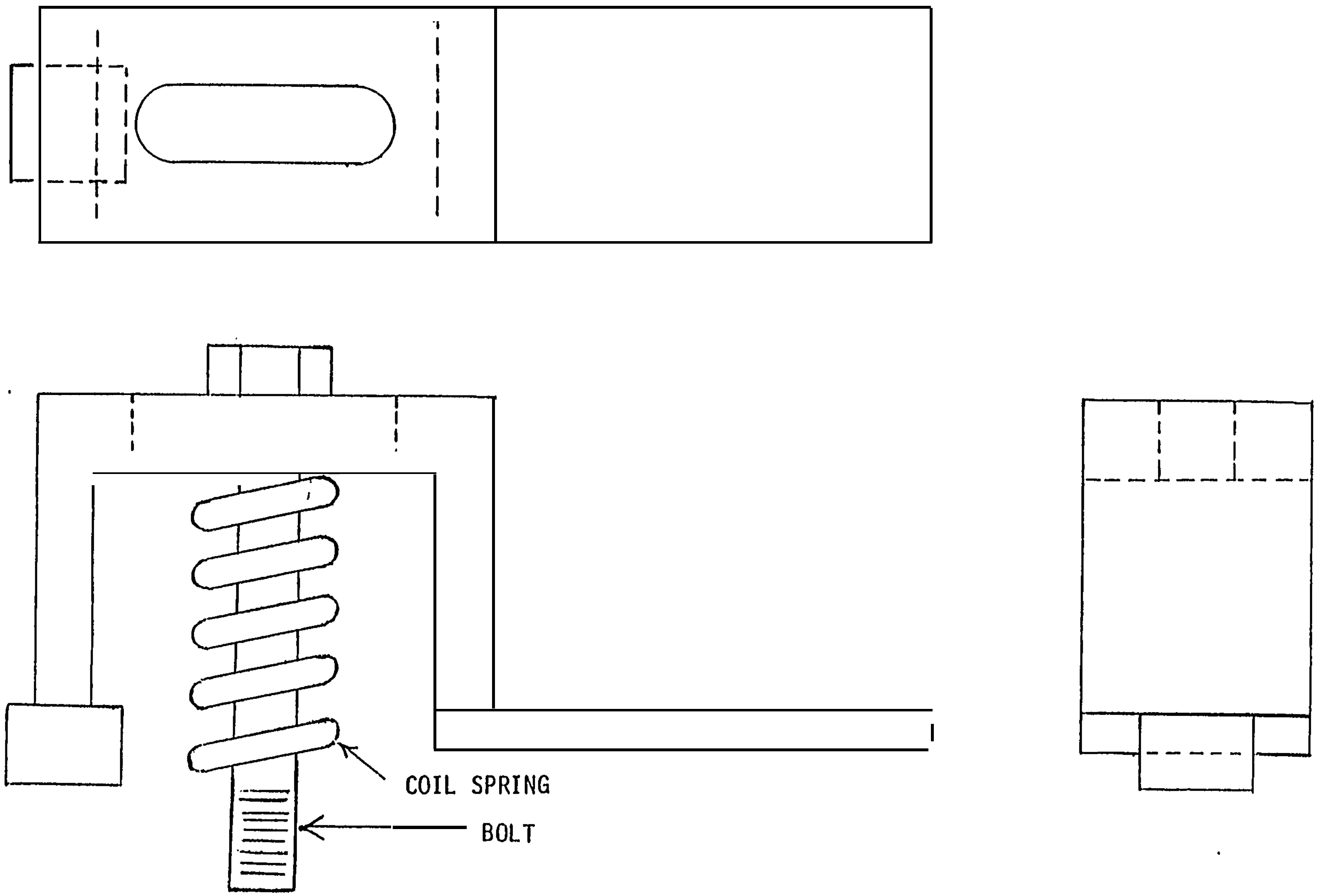
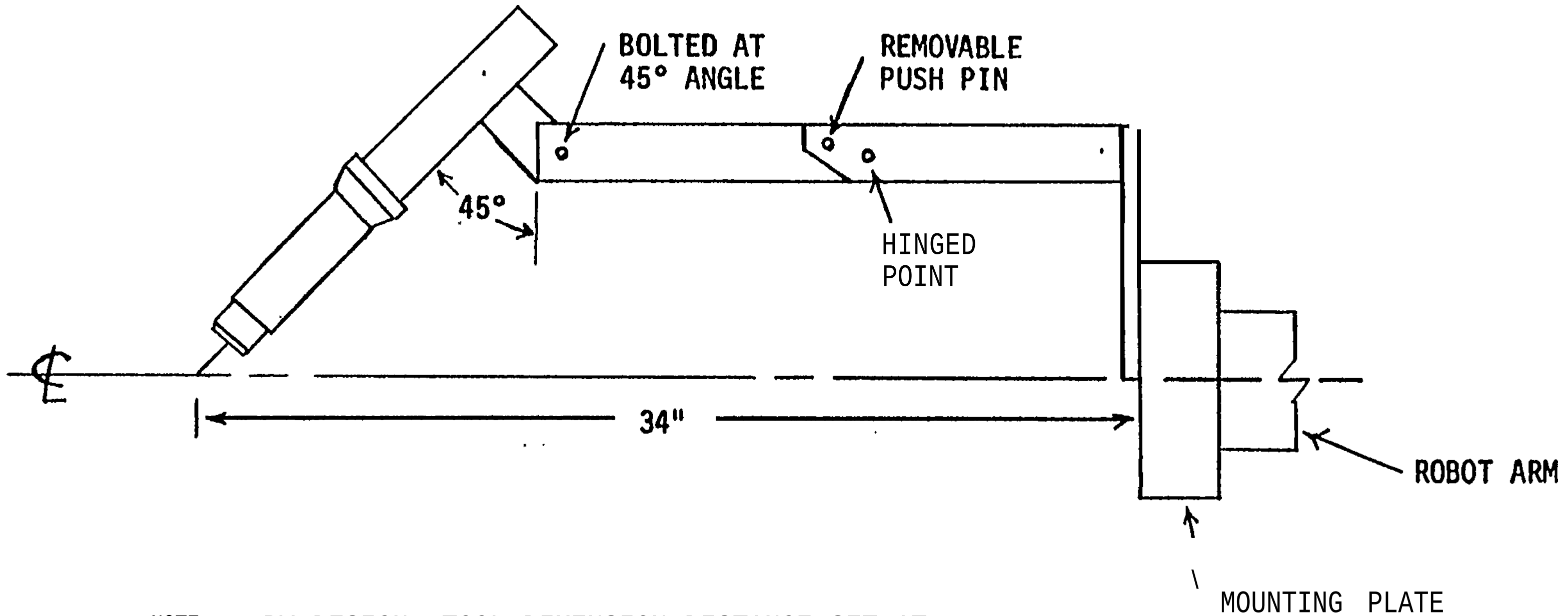


FIGURE O

TOOL DIMENSION EXTENSION



NOTE : BY DESIGN, TOOL DIMENSION DISTANCE SET AT 24″ MAX, WILL EXTENDTO 34″ BY ADDING ABOVE HINGED BRACKET ASSEMBLY.

FIGURE 11

4.4.2 Torch Assemblies (cent'd)

torch mount which was procured and installed. The torch mount features a sensing switch capable of shutting the operation off and a spring loaded bracket to reposition the torch after it has been disturbed. Both of these features eliminate previously operator-performed tasks. See Exhibit 9. No single torch mount design will provide torch access to all possible joint configurations. The most universal mount used to date is simply a straight bracket with a joint at the torch end for angle adjustments.

It is most important to note that whenever the torch is moved, the torch tip must always be positioned on the center-line of the end effecter and the correct tool dimension input into the control unit. The positioning is best accomplished by fabricating a simulated torch position gage that mounts to the end effecter and provides an accurate, consistent reference point. All previous programs will require modific-ation to conform to the new tool dimension prior to running them.

4.4.3 Torches

The physical size of the torch should be small for weight and access considerations. The length of the torch nozzle assembly most frequently used is four inches; however, both a three and five inch nozzle assembly have been useful in certain situat-ions. This identifies the desirability of having easily interchangeable torch nozzle assemblies. A straight barrel torch mounted on a hinged bracket at a 45° angle was found to be the most effective for this application. See Figure 11. A 22° torch angle was evaluated and found to be very adequate but not quite as universal as the 55° torch angle in terms of access. The 22° torch angle offers the best access to corners and flat welds as they are positioned by the positioner.

A numberof different torches have been evaluated. Of these. two have proved most successful based on the above criteria and considerations: 1) Machine Specialties D & F, and 2) Binzel Robo 450.

4.4.4 Evacuation

4.4.4.1 Performance

4.4.4.1.1 MachineSpecialties D & F - The D & F water cooled torches consist of two models, a 55° torch angle and a straight barrel both with interchangeable nozzle assemblies of 3-4-5 inches. The torch is compact .

and streamlined in design and has performed well without a major failure or breakdown. See Exhibit 10.

4.4.4.1.2 Binzel Robo 450

The Binzel Robo 450 water cooled torch was designed by Binzel specifically for robot welding applications. See Exhibit 11. However, the coolant does not circulate as far down the barrel assembly as the D & F torches resulting in a hotter nozzle that collects more spatter. This can be overcome by using an automatic cleaning unit (which will be discussed 1 ater) designed to be used with this torch. The torch evaluated had a 22° torch angle and three inches of nozzle assembly after the bend. This angle is acceptable though not as effective as the D & F 55° torch angle. Torch lengths cannot be varied unless the complete torch assembly is changed. The Binzel torch does not have interchangeable nozzle assemblies. Binzel 's unique cable connection design makes this change a fast and easy operation. The Binzel torch is smaller and more compact than the D & F which is an advantage. Steel wire runs through the 55° torch angle without much of a binding problem. Aluminum wire has more of a tendency to bind, causing the weld system to shut down. Two other factors affect the binding problem. The current wire feed system is a push type; the wire drive unit is mounted on the robot arm and pushes the wire through the cable and torch (approximately 7 feet). A push-pull wire drive system incorporates a pulling motor in the torch handle and reduces the chance of the wire binding. This system should be evaluated.

The second consideration is the length of the cable between the wire drive unit and the torch.

4.4.4.1.3 Hobart WCG 600

The WCG 600 water cooled torch has a 45° torch angle. See Exhibit 12. This torch was found to be inadequate in most applications. The nozzle retaining nut interfered when getting into/out of tight corners. A slender profile is required in these areas.

4.4.4.2 Maintenance and service

Normal servicing of torches was required. Addition of liners, tips, nozzles, etc., were replaced as needed.

4.4.4.3 Recommendation

4.4.4.3.1 Torch Assembly

The assembly should be designed to be as streamlined as possible,especially at the torch end. Any excessively large pieces of hardware at this end will limit the accessibility of the torch to the workpiece.

The assembly should be rigid in all positions; any deflection will affect the arm's repeatability and the quality of the weld. The assembly should also be rigid enough to minimize any unwanted vibration when the robot is operating, especially in the weave mode.

4.4.4.3.2 Torch

Torch cleaning during the welding operation has been a problem. It is important for smooth operation of the system that spatter not be allowed to build up on the inside of the nozzle. If this occurs, the shielding gas coverage can be disturbed and thus affect the quality of the weld, or the arc can short circuit to the nozzle causing the weld system to shut down. Use of a chrome-plated nozzle will minimize spatter buildup. Presently, the operator manually cleans the nozzle and applies antispatter spray during table movements.

An automatic torch cleaning system, designed for robot welding operations by Binzel, has been procured, but not yet evaluated. See Exhibit 13. The fully automatic system is designed to accept the torch nozzle into a cleaning unit at pre-prograirrned intervals. The unit cleans the nozzle and applies a coat of antispatter fluid. Without such a system, much of the productivity gained by automation is offset by the need for the operation to be constantly monitored by the operator.

The length of the cable between the wire drive unit and the torch should be minimized by providing only enough cable so that the arm may be fully extended to its working limit.

The operator usually works in close proximity to the torch, often just after a weld has been performed. To insure safety and not delay the operation, the torch design should provide water cooling through the nozzle.

5. Programming

5.1 General

Part programing is the most critical aspect of the robot welding operation affecting its successful application in shipbuilding. As verified by a ship part survey, shipbuilding is characterized by its variety of small batch, often unique assemblies. In the case of a single unique part, the programming time can represent as much as 90% of the total processing time.

The system software used to generate the program, must be completely understood by the operator to maximize its capabilities. Part programming time is usually the determining factor when time is used to justify the advantage of robot welding versus manual/semi-automatic welding.

For purposes of this evaluation, programming time is defined to be the time required to:

° Plan and input the positioner table movements
° Develop the part program, including teaching the path and inputting appropriate parameters
° Test running the program, including modifications

Part programing is primarily a mental function. To produce the desired results requires the coordination of two individually complex functions--welding and operating a robot. The selection of a top quality welder to train as a robot operator was desirable to preserve the integrity of the welding process while allowing the operator to concentrate on the programming function.

These are three tasks that should be coordinated to develop a complete part program:

° Select and input positioner table movements
° Maniuplate the rokot arm over desired paths and input points
° Input variable information that directs robot operation and welding operation

5.2 Positioner Table Movements

Table movements are planned in conjunction with the weld sequence prior to actual path programming. Each movement is recorded in the control unit as part of a separate sequence. This sequence is then called on throughout the main part program, to initiate the next movement. This method of separate table movement programing is preferable to programming movements during the part programming function because the weld is easier to plan and there is less chance for error. Table movement planning and programming time with current equipment is less than 10% of the total programming time. The time required for this operation is most dependent on the speed at which the table moves and the experience of the operator in selecting proper weld sequences.

5.3 Path Teaching

The CM-T3 rcbot is a point-to-point servo-controlled machine. This means the robot is designed to follow a straight line path between any two programmed points. To program a straight line weld segment requires that the torch (mounted on the robot arm) be properly located at the starting point of the weld and the orientation of the torch relative to the joint be correct. The comand is then issued to the control unit to "remember" the position of the robot's arm; in this way it can return to the same position when instructed. The robot arm is then maneuvered to the end point of the weld segment and the torch again oriented in its proper position (not necessarily the same orientation as the beginning). This point is then programmed "remember" as before. The path followed (during the teaching process) when going from start-to-finish point is not important. When instructed, the robot will return to the start point and move, at the assigned speed, in a continuous straight line to the ending point. A significant amount of time can be saved by positioning the part such that its right angle joints are located along the natural axis of the robot's motion. This allows for simple and fast manipulation of the arm between points of these axes.

After each path is taught, the robot is returned to the starting point and the path run as it would be if actually welding. This gives the operator a chance to check the torch orientation as it travels between the programmed points. This is a time-consuming but necessary operation. Often, the path must be slightly modified by adding some intermediate points because the joint is not perfectly straight. New systems with the ability to automatically adjust the robot's motion for variations in the joint geometry will eliminate the need to go through this exercise and save considerable time.

5.4 variable Input

When any potnt is defined as being part of a path, the operator must input a variety of variable information that is used by the system to direct the robot and/orwelding operations. This control information requires input at the control unit console and includes:

- Robot operation information
- Weld operation information
- System operation information

5.5 Evaluation

5.5.1 Performance

The most time-consuming aspect of programming a welding path is orienting the torch into proper position relative to the joint. Proper torch orientation is absolutely critical to the outcome ofa weld. To insure proper positioning, the operator must work close to the tip of the torch, make very fine adjustments to its position, then check the orientation from all possible angles. To significantly reduce programming time, new robot control technology will have to address this torch orienting problem. The conventional button box control device, used to direct the motion of the robot arm, is adequate but slow even for an experienced operator. See Figure 12. Desired motion is accomplished by depressing one or more of twelve possible buttons controlling six different motions. Movement in two or more directions simultaneously requires a reasonable amount of thoughtand skill. The safest, surest, and most time-consuming sequence of motion is to activate one direction at a time, especially in tight places and around a workpiece. Faster, more intuitive methods of directing the robot arm will certainly contribute to more efficient path teaching.

There are three coordinate systems available in which the robot arm may be manipulated while defining the points of a path: 1) cylindrical; 2) rectilinear, and 3) hand coordinates. The rectilinear teach mode has proven to be the most intuitive system of motion and is used most often.

Varying amounts of information are required depending on the function to be performed. This input represents a significant contribution to total program time. Initial data indicates a range of 5 to 11 program points per segment with an average of about 8 points per segment. Number of points varies with the length and complexity of the weld segment.

The time the operator spends traveling between the workplace and the control console is dependent on the distance between the two areas. This can be minimized by careful layout of the work station and/or programing capabilities of the teach pendant.

5.5.2 Recormnendation

Many of the program points that define a single segment and the operations to be performed on it are consistently in the same order and of the same type. New software developments should allow the input of a block or standard sequence of points with a simple comnand. The sequence should be easily edited.

If the operational commands could be predefine in this fashion, and only the torch location and orientation require defining, considerable programming time could be saved.

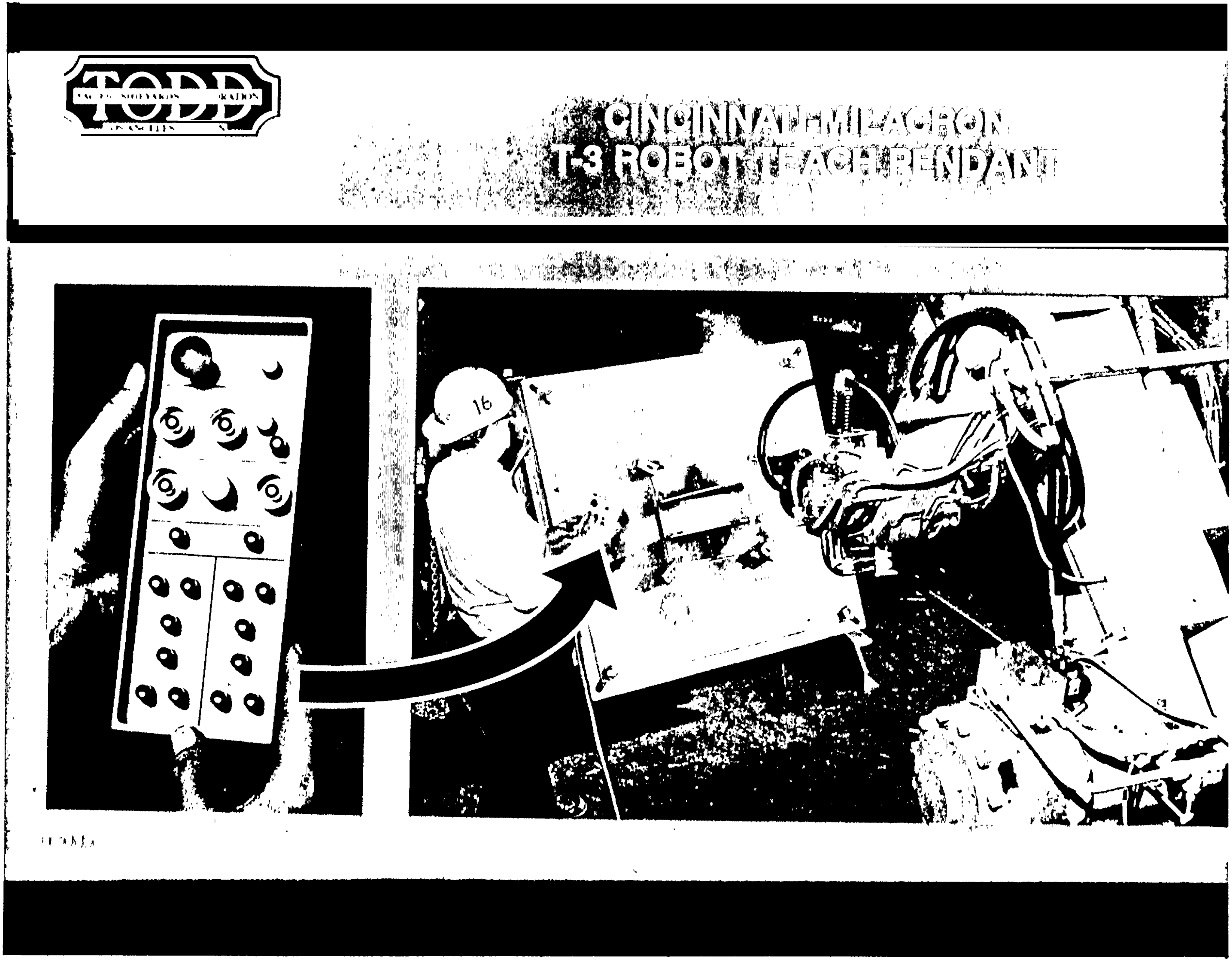


FIGURE 12

5.5.2 Recommnendation (cont'd)

A current-capability of the programing system, that needs only refining to be a very-useful tool, is the automatic "mirror image" function. The function will automatically generate a mirror image ofan existing set of program points. Its limitations now are that it does not translate table movement, it only translates points about the robots X axis, and the existing sequence of points are deleted and replaced by the mirrored sequence. Such a function would be most efficient when programming symmetrical parts, and port and starboard pairs; both of which are common in shipbuilding. This function or one similar should be considered in the development of new software packages.

It is recommended that future software developments include a menu of automatic "table movement commands relating to common movements. This will reduce the time required to perform the operation and further automate the system.

In sunmary, efficient programming (operator and software interaction) is dependent on a flexible software system that capitalizes on the consistencies of the welding operation and the operator's complete knowledge of that system.

Currently, this operation is entirely an operator-dependent function. The robot and control unit do not perform any function unless taught to do so. As a result, the system's efficiency and productivity is more dependent on the operator, his ability, knowledge and experience, than any other single factor. The machine should be designed to do most of the work; it currently falls far short of this goal.

6. Robot Welding Operation

6.1 General

The welding operation ofa robot welder is similar in most respects to conventional methods thou h more sensitive. Robot welding is a fully automatic (noninteractive operation, requiring that all aspects of the operation and factors affecting it are correct.

The quality of any weld is dependent on the weld parameters and execution of those parameters. A good manual welder knows the welding parameters to use to produce a quality weld on a given piece of material, and has the ability (advantage) to automatically adjust certain parameters to insure the weld quality. In contrast, the robot welder does not currently have any welding process control feedback capable of adjusting its weld parameters to insure quality. The robot does, however, have the advantage over the manual welder in maintaining the programmed weld paramters precisely (particularly with respect to travel speed). The result of these considerations is that the robot can produce a quality weld consistently, if and only if, the weld paramters for the precise task at hand are known.

This identifies the need to develop detailed documentation of weld parameters for every anticipated welding application if the robot welder is to be efficiently utilized in a versatile production mode.

6.2 Weld Parameters

Candidate ship parts and foundations for robot welding are made up of mild steel and aluminum. A ship part survey for FFG-7 class vessels identified material thicknesses of 3/16″, 1/4″, 3/8″ and 1/2″ to be common, the most common being 1/4″. Weld parameters for welding these materials and material size should be developed first. Parameters for other materials and sizes may develop as time and need dictates.

The most common joint type encountered in small ship part and foundation construction was identified to be the tee joint, which required a fillet weld. See Exhibit 14. The use of a positioner allows the piece to be positioned so most all fillet welds can be made in the flat position. Parameters for this orientation form the real working base of the robot welding operation.

A ship part survey also identified the following joint types: butt joints, lap joints, and corner joints. Similarly, the positioner allows these joints to be oriented in their ideal welding orientation.

The ability to position each joint in its ideal orientation for welding with the positioner should not imply this is always the most desirable. A small, yet significant, amount of time is committed to the total process time with each table movement; this includes table programing time and actual movement time. Other joint orientations should be investigated for possible use based on the weld quality achievable. Depending on the quality and repeatability of these types of welds, if more than one joint orientation can be suitably welded from a single table movement, increased efficiency may be achieved. The welding procedures and filler metal utilized during production welding are shown in Exhibits 15, 16, 17 and 18. These procedures are for automatic FCAW on low and medium carbon steels and for butt/fillet welds on aluminum. Weld size and quality is very sensitive to torch travel speed. The Ct?-T3 robot is designed to move the torch tip at a programmed travel speed. Torch tip location is defined (input) by the tool dimension function of the robot control system. It must be positioned on the centerline of the robot end effecter.

If not properly positioned and defined, the resulting travel speed will be slightly higher or lower than the programmed travel speed, if any rotations are part of the programmed movement.

To insure accurate and repeatable weld parameters, always be sure torch position and tool dimension are correct.

Within the domain of single joint type and orientation, there are conditions that may require slightly different weld parameters. These should be investigated and documented. Generally, one of the following three conditions exist:

- A straight weld requiring no change in torch attitude (no rotations required)
- A weld ending in a corner which requires the torch tip be rolled into the corner
- A corner-to-corner weld which requires the torch tip to start in the corner, be rolled out, then rolled into the ending corner

Any changing relationship between the torch and the flowing weld puddle (usually experienced in the last two conditions above) can affect the final weld. This may be corrected by specifying slightly different weld parameters at points along the path. Distortion of the material, by previously deposited welds, can affect the outcome of subsequent welds. It is therefore mandatory that all new parts have welding sequences/parameters developed to minimize distortion.

It is often desirable to control the weld puddle at the starting and ending point of a weld segment by varying the weld parameters. A "hot" (high amperage/voltage setting) weld parameter just at the beginning ofa weld will bring the surrounding area to the desired temperature quickly, allowing the weld puddle to flow and insuring a proper start. A "cold" (low amperage/voltage setting) parameter at the end of a weld will reduce the temperature and keep the weld puddle from flowing too freely and spreading out during the filling of the craters. These methods are highly desirable when welding aluminum parts.

The delay function is often used to fill the crater at the end ofa weld segment. Delay time must be investigated for different welds and conditions.

These and other considerations that make welding as much an art as a science are often performed automatically by an experienced welder. The robot, however, must be programmed to perform each detail, and so the parameters to achieve each condition must be known.

6.3 Welding Process Variables

A primary advantage of the robot welder is its ability to maintain constant weld parameters during the welding process. This contributes considerably to improved consistent quality and appearance of robot welds compared to manual welds. The ability to maintain constant travel speed also contributes to better control over heat distortion.

The welding robot does not have the ability to recognize disruptive conditions in the joint and correct for their presence. This often leads to automatic shutdown of the weld process when such conditions are encountered. Shutdowns usually occur due to loss of arc or wire jamming.

When the torch ‘encountered a non-conductive surface, usually flux, slag, or some other impurity, the result is often loss of arc which can result in system shutdown. When an oversize tack weld is encountered, the wire can jam as it passes also causing a system. shutdown.

Both of these occurrences can be minimized by careful joint preparation. The care with which a joint must be prepared for robot welding is greater than that of other methods of welding, though not significantly different. Proper joint preparation does not, however, insure uninterruption of the weld process.

Excessive spatter accumulation can cause process interruption on even a properly prepared joint. Likewise, beginning a new weld on top of a previous slag covered weld has the potential to cause shutdown if no arc can be struck through the existing slag. New high silicon slagless wires are being developed for robot utilization. As of this writing, we have not evaluated any of these new wires. Possible advantages over slag type wires could be: less frequent arc restarting problems, no slag to remove, and increased productivity. Currently, there are no automated systems to guard against such disruptions. Careful programming and sequence planning can help minimize their occurrence.

A fit-up gap of a size a slarge or larger than the wire being used can cause the system to shut down due to loss of arc. One instance occurs on start when the wire begins to feed, it feeds through the gap and no arc is struck. A second occurs during the weld process when the liquid weld puddle seeps through the gap, burning a hole as it goes, the wire feeds through, and the arc is lost. Accurate fit-up or manual filling of such gaps prior to robot welding will eliminate this occurrence. Robot control process feedback, when developed, could be used to correct these situations.

A less frequent cause of shutdown is caused by buildup of spatter on the inside of the nozzle. If concentrated, the spatter can provide enough of a metallic surface to cause the arc to be struck to it, thus shorting out the system. This is remedied by frequent cleaning of the torch nozzle during the welding operation.

A weld process shutdown requires approximately five to ten minutes to correct. Currently, these failures in the weld system do not occur with enough frequency to be considered a major problem. The care and attention required to avoid them demonstrates the required attention to detail necessary to make the entire operation run efficiently.

The weld sequence selection is as important for the robot welder as for any other welding method, if not more. Some degree of distortion is to be expected with any welding process. In the robot welding operation, distortion can alter the path of a previously programed weld segment enough to render the subsequent weld unacceptable. Without the ability to track a seam and correct for variation in the path, the only solution is to program only a few segments, weld them, and continue in this manner until the part is completed.

This kind of sequence is not repeatable, which drastically reduces the efficiency of the system. Good sequence planning must be part of the robot welding operation to minimize this shortcoming.

The positioning of more than one part on the positioner, when possible, will also help reduce distortion. The operator can program weldments alternately between parts, allowing one to cool while the robot performs on another. This is desirable when possible. Multiple positioners will make this capability available to larger parts. On segments that are long and cannot be welded in one pass for distortion reasons, programing care will be required to insure adjacent weld segments overlap enough to provide an acceptable weld. This will require beginning the new weld slightly (1/16") behind the end of the previous weld.

In summary, the robot welding operation can produce superior welds in a shorter period of time compared to other methods. To realize these advantages requires more attention to detail and more precise definition of the operation.

7. Cost/Application

7.1 Production Work Cost Comparisons

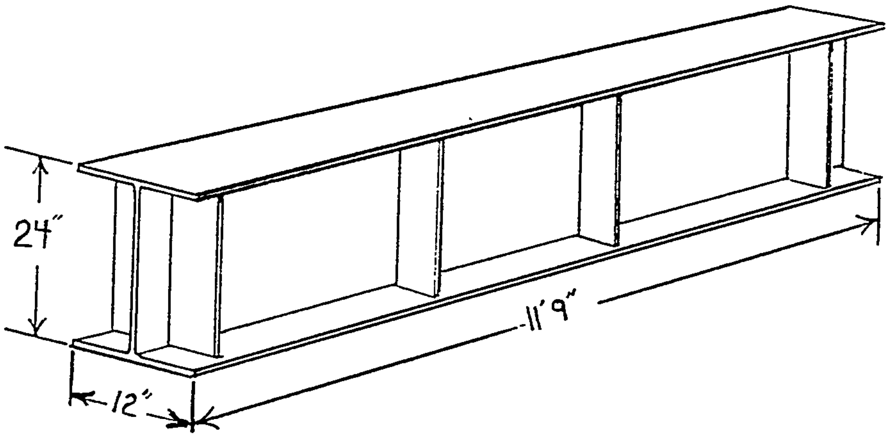
Recent production work has involved the CM-T3 robot in welding components for a ship lift system. This lift system is made up of quite a few similar structures which lend themselves well to automation. Tables 1, 2, 3 and 4 show data gathered concerning prograrrrning/fabrication time and comparisons to typical fabrication methods .

7.2 Process Costs

Fillet welding has already been identified as one of the primary types of welding applications for robot automation in shipbuilding. Cost per pound of weld metal deposited for various size horizontal fillet welds are compared for three welding processes: flux cored arc welding (FCAW), shielded metal arc welding (SMAW), and gas metal arc welding (@IAW). The comparisons are shown in Table 5.

FABRICATION TIME BREAKDOWN

STRUCTURAL BEAM



STRUCTURAL BEAM

Weld Length/Size:

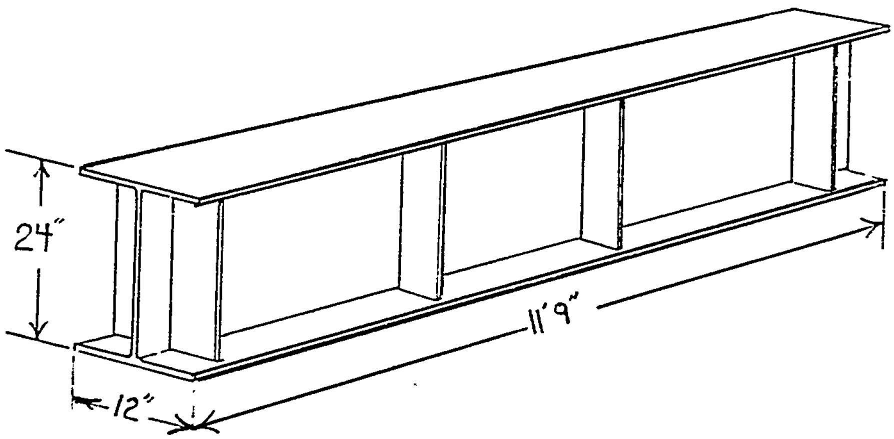
52′ 6″ of5/16° Fillet
16′ 4″ ofl/4° Fillet
4′ 9″ of 3/8″ Fillet

CMT-3	
ACTIVITY	MINUTES
Programming	108
Joint Prep./cleaning	2
Welding	103
Load/unload	10
Other	
Total	223

TABLE 1

WELDING COST COMPARISON

STRUCTURAL BEAM



Part 1: STRUCTURAL BEAM

WELDING METHOD	PROGRAMMING TIME (min.)	TOTAL WELDING TIME (min.) (1&3)	COST PER BEAM (labor) (2)
Semi-Automatic FCAW	N/A	720 (12 hrs.)	$360.00
Robot FCAW	108	223 (3.7 hrs.)	$111.50

NOTES:

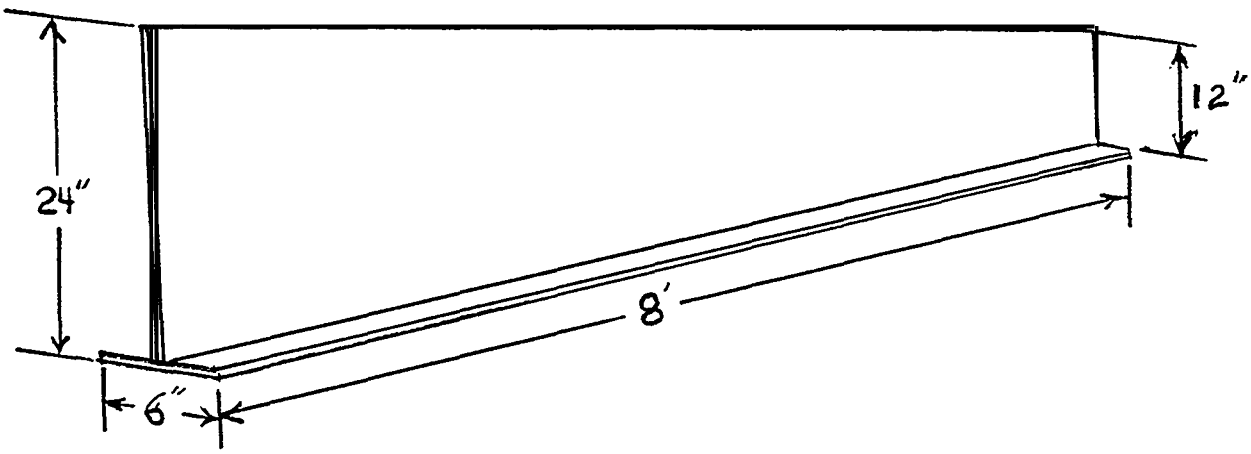
1. Includes: Welding, loading/unloading, crane lift and programming.

2. Based on 30$/hr. and not including equipment cost.

3. The following fillet welds were deposited (lengths are approximate): 52′ 6″ of5/16″,16′ 4″ of 1/4″, and 4′ 9″ of 3/8″,

TABLE 2

WELDING COST COMPARISON - RAIL SUPPORT



Part 2: RAIL SUPPORT

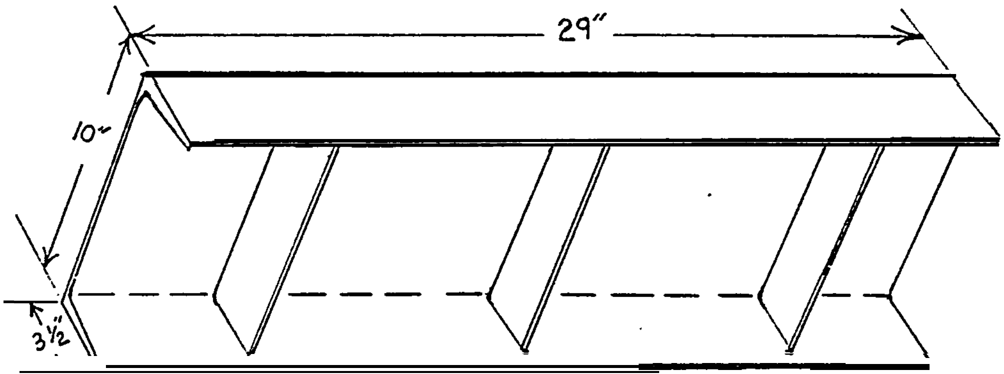
WELDING METHOD	PROGRAMMING TIME (min.)	TOTAL WELDING TIME (min.)	COST PER BEAM (2) (labor)
Semi-Automatic FCAW	N/A	120	$60.00
Robot Automatic	17	37	$18.51

NOTES:

1. Includes: Welding, loading/unloading, crane lift and programming.
2. Based on 30$/hr. and not including equipment costs.
3. 16' 10" of5/16" fillet weld deposited.

TABLE 3

WELDING COST COMPARISON - WHEEL ASSEMBLY SUPPORT



Part 3: WHEEL ASSEMBLY SUPPORT

WELDING METHOD	PROGRAMMING TIME (min.)	TOTAL WELDING TIME (1) (min.)	COST PER BEAM (2) (labor)
Semi-Automatic FCAW	N/A	48	$24.00
Robot Automatic	1	9	$4.5

NOTES :

1. Includes: Welding, loading/unloading, crane/boom lifts and programming.
2. Based on 30$/hr. and not including equipment costs.
3. 7′ 6″ of 5/16″ fillet weld deposited.

TABLE 4

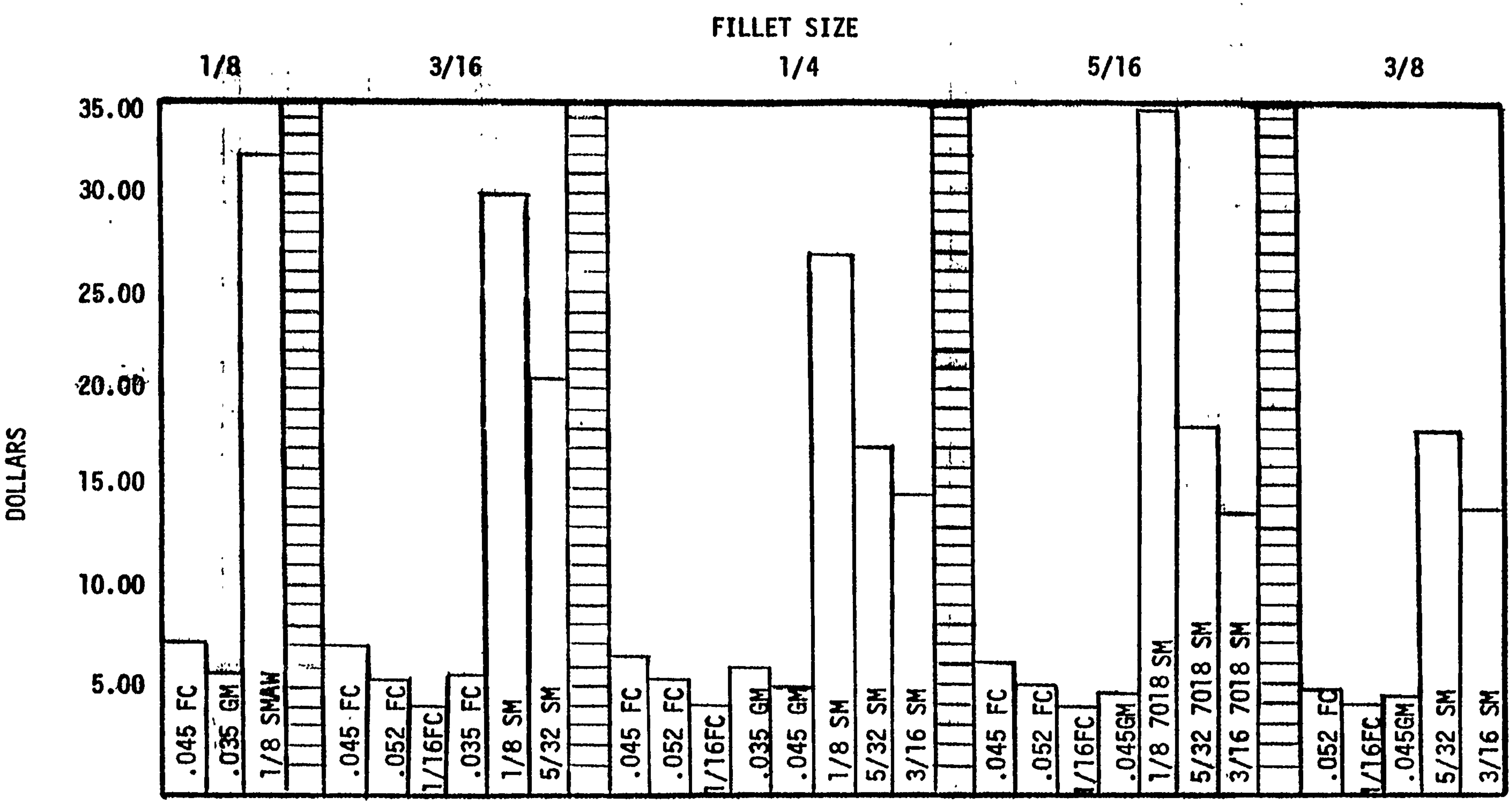
COST PER POUND OF WELD METAL DEPOSITED

HORIZONTAL FILLET WELDS

FCAW (FC) = E71T-1

GMAW (GM) = ER70S-3

SMAW (SM) = E7018



Vertical figures denote electrode diameter.

TABLE 5

7.2 Process Costs (cont'd)

Work with grooved butt joints was started but did not involve enough parts to make any valid comparisons at this time. However, the work performed to date indicates that multiple pass grooved butt joints can be accomplished by the robot welding system with significant cost advantages over manual and semi-automatic welding operations. Welds that were made were manually deslagged. Newly developed slagless flux cored welding electrode should make this operation even more cost effective.

7.3 Cost Estimating Worksheets

Simple cost estimating worksheets are used to determine the total cost per pound of deposited weld metal for three different situations. See Tables 6, 7 and 8. These worksheets can give a quick comparison between welding methods, but do not account for variables such as material handling, jig and fixturing, workpiece fitup tolerances, etc.

8. Material Handling

8.1 General

Efficient material handling capabilities are important for **a** system designed to process quantities of parts. The robot and positioner were located to provide space on both sides of the positioner for incoming and completed parts. Many of the parts to be processed are small and delivered on pallets. Tables of sufficient size and strength should be located near the table positioner to accommodate these pallets of parts, thus relieving the operator offending to lift the parts from the flookto the table. For **larger** parts, the work station is located in an area serviced by an overhead crane of sufficient capacity to handle the maximum weight allowable on the table positioner.

8.2 Evaluation

8.2.1 Performance - Not applicable

8.2.2 Maintenance and Service - Not applicable

8.2.3 Recommendation

As the system becomes less operator-dependent, semi-automated or mechanized material handling equipment should be considered and evaluated.

WELD METAL COST WORKSHEET

PREPARED FOR: CMT-3 ROBOT PROJECT PREPARED BY: D.A. LANG, JR. DATE: 12/15/83

FORMULAS FOR CALCULATING COST PER POUND DEPOSITED WELD METAL	PROPOSED METHOD COST CALCULATION	PRESENT METHOD COST CALCULATION	PROPOSED METHOD VS. PRESENT METHOD *COST REDUCTION - COST INCREASE +
	CMT-3	7018 5/32"	
	1/16" dia. 30# spool	50 lb. cans	
LABOR & OVERHEAD = LABOR & OVERHEAD COST/HR ÷ (DEPOSITION RATE (LBS/HR) X OPERATING FACTOR)	30.00 / (9.9 X .70) = 30.00 / 6.93 = 4.33	30.00 / (3.78 X .30) = 30.00 / 1.13 = 26.55	-22.22
ELECTRODE: = ELECTRODE COST/LB ÷ DEPOSITION EFFICIENCY	1.20 / .87 = 1.38	.48 / .74 = .65	+ .73
GAS: = GAS FLOW RATE (CU FT/HR) X GAS COST/CU FT ÷ DEPOSITION RATE (LBS/HR)	45 X .06 / 9.9 = 2.7 / 9.9 = .27	X = = N/A	+ .27
SUM OF THE ABOVE	TOTAL VARIABLE COST/LB DEPOSITED WELD METAL $ 5.98	TOTAL VARIABLE COST/LB DEPOSITED WELD METAL $ 27.2	$ -21.22

*COST REDUCTION INDICATED BY MINUS SIGN

NOTES:

1. Based on operator factors of 70% for robot and 30% for SMAW.
2. Figures may vary per application.

TABLE 6

WELD METAL COST WORKSHEET

PREPARED FOR: CMT-3 ROBOT REPORT

PREPARED BY: D.A. LANG, JR. DATE: 12/15/83

FORMULAS FOR CALCULATING COST PER POUND DEPOSITED WELD METAL	PROPOSED METHOD COST CALCULATION: FCAW (ROBOT) 1/16" 30# spool	PRESENT METHOD COST CALCULATION: FCAW (SEMI-AUTOMATIC) 1/16" 30# spool	PROPOSED METHOD VS. PRESENT METHOD *COST REDUCTION - COST INCREASE +
LABOR & OVERHEAD = LABOR & OVERHEAD COST/HR / (DEPOSITION RATE(LBS/HR) X OPERATING FACTOR) =	30.00 / (9.9 X .70) = 30.00 / 6.93 = 4.32	30.00 / (8.2 X 45) = 30.00 / 3.69 = 8.13	-3.81
ELECTRODE: = ELECTRODE COST/LB / DEPOSITION EFFICIENCY =	1.20 / .87 = 1.38	1.20 / .87 = 1.38	± 0
GAS: = GAS FLOW RATE (CU FT/HR) X GAS COST/CU FT / DEPOSITION RATE (LBS/HR) =	45 X .06 / 9.9 = 2.7 / 9.9 = .27	45 X .06 / 8.2 = 2.7 / 8.2 = .33	- .06
SUM OF THE ABOVE	TOTAL VARIABLE COST/LB DEPOSITED WELD METAL $ 5.97	TOTAL VARIABLE COST/LB DEPOSITED WELD METAL $ 9.84	$ -3.87

*COST REDUCTION INDICATED BY MINUS SIGN

NOTES:

1. Based on operator factor of 70% for robot and 45% for FCAW.
2. Figures may vary per application.

TABLE 7

WELD METAL COST WORKSHEET

PREPARED FOR: CMT-3 ROBOT PROJECT PREPARED BY: D. A. LANG, JR. DATE: 12/15/83

FORMULAS FOR CALCULATING COST PER POUND DEPOSITED WELD METAL	PROPOSED METHOD COST CALCULATION FCAW 1.16" 30# spool	PRESENT METHOD COST CALCULATION SMAW 5/32" 50 lb. cans	PROPOSED METHOD VS. PRESENT METHOD *COST REDUCTION - COST INCREASE +
LABOR & OVERHEAD = LABOR & OVERHEAD COST/HR ÷ (DEPOSITION RATE(LBS/HR) X OPERATING FACTOR)	30.00 / (8.2 X .45) = 30.00 / 3.69 = 8.13	30.00 / (3.78 X .30) = 30.00 / 1.13 = 26.55	-18.42
ELECTRODE: = ELECTRODE COST/LB ÷ DEPOSITION EFFICIENCY =	1.20 / .87 = 1.38	.48 / .74 = .65	+ .73
GAS: = (GAS FLOW RATE (CU FT/HR) X GAS COST/CU FT) ÷ DEPOSITION RATE (LBS/HR) =	(45 X .06) / 8.2 = 2.7 / 8.2 = .33	X = = N/A	+.33
SUM OF THE ABOVE	TOTAL VARIABLE COST/LB DEPOSITED WELD METAL $ 9.84	TOTAL VARIABLE COST/LB DEPOSITED WELD METAL $ 27.2	$ -17.36

*COST REDUCTION INDICATED BY MINUS SIGN

NOTES:

1. Based on operator factor of 45% for FCAW and 30% for SMAW.
2. Figures may vary per application.

TABLE 8

9. Group Technology Analysis

9.1 Selection of Parts

During the course of the evaluation, a survey was conducted to learn more of the nature of small parts and foundations found in this shipyard, Data to be compiled on such parts included:

- Material and material thickness
- Quantity of similar parts
- Fit-up and tolerances between similar parts
- Number of weld segments
- Total welding inches
- Types of joints

Mild steel and aluminum parts were surveyed. One criteria for a part to be included in the survey was that there be at least two of the same parts present, this included port and starboard pairs. It is valuable to note that this criteria excluded from the survey a significant numberof parts in evidence (estimated at over 50%).

9.2 Survey Sunmary

- Number of parts surveyed - 75
- Material - mild steel
- Most common material thickness - 1/4″
- Other material thicknesses - 3/16″, 3/8″, and 1/2″
- Average quantity per batch - 8pieces
- Mean quantity per patch - 4 pieces
- Maximum quantity per batch - 100+ pieces
- Minimum quantity per batch - 2 pieces (specified)
- Most comnon joint type- straight fillet
- Number ofweld segments
  - Small brackets and fixtures amounted to approximately halfof the parts surveyed.
  - They consisted of2-6 weld segments of 2″-10″ each.
  - Larger assemblies consisted of15-40 weld segments each, ranging from 2″-24″ in length.
- Total Welding Inches
  - Small brackets and fixtures ranged from approximately 10″-40″ of weld per piece.
  - Larger assemblies ranged from approximately 50″-350″ weld per piece.
- Fit-Up
  - The fit-up variation in parts where variation would affect repeatability of the surveyed parts ranged from 1/32″-1/8″. The most common variation was 1/16″.

Approximately 90% of the similar parts included in this portion of the survey showed fit-up variation.

The results of this survey were intended to provide some useful data on the kinds of small assemblies evident in this shipyard and were not intended to define any parameters of a small part welding operation. Upon completion, this information was used to guide the design of test parts for the robot.

9.3 Physical Limits and Access

A clear definition ofwhat physically can and cannot be done by the system is important to evaluate. This involves learning the limitations of the equipment and physical work space aswell as limits of part size, characteristics and accessibility. The objective being to quantify these limiting characteristics so this information may be effectively communicated, and used to identify robot parts.

The robot's welding enveJope defines the limit of reach of the robot arm. The effective reach has been extended by mounting the torch approximately 24.0 inches from the end effecter. In addition, this capability has been extended another 10 1/2" for various applications, thus extending the working envelope slightly. See Figure 11. This improves access as well as extending arm reach.

The welding process requires that the torch angle be correct at all times, which is not always achieved when the arm is in a fully-extended position. Therefore, the limiting values of parts size that will fit on the positioner table and remain inside the robot's working envelope are slightly less than the boundaries that define the envelope. The work envelope available for the robot to reach is approximately 1000 cubic feet.

A short series of tests were conducted to determine some limiting values of torch accessibility in the way of obstructions. It was found that the torch and torch mount assembly could be properly positioned into a space not less than four inches wide when bounded on two sides. The depth of such access is limited by the length and slenderness of the torch mounting bracket; in this case approximately 20".

The torch (nozzle and barrel) could be properly positioned into a space not less than two inches wide when bounded on the sides. The torch could be positioned and a suitable weld produced when the angle between two adjoining plates was 35° or greater.

The ability to properly orient the torch is the determining factor for access considerations; there is no compromise in this regard.

A test was conducted to determine the effect of fit-up variation on the welding operation. Four similar parts were fabricated. The first was positioned, indexed, programed, and welded. Subsequent parts were positioned at small increments away from the original programmed/indexed part location and welded with the same program. One sixteenth inch variation from the established programmed/indexed points proved acceptable; greater than 1/16" variation produced unacceptable welds.

Joint fit-up tolerances were also found to be critical. Joint fit-up gaps 1/16" or greater resulted in poor quality welds and/or equipment malfunctions. To fully utilize the capabilities of the robot, it is essential that criteria be developed on which to base robot application judgments. This criteria should be developed, in a reasonable amount of time with some degree of confidence, for a wide variety of parts.

The objective was to develop some simple relationships that could be used to determine the approximate time required to completely process a part based on a few easily determined independent characteristics (variables) of the part such as:

- Number of weld segments
- Length of weld segments
- Numberof planes in which segments are oriented
- Total weld inches

Time was selected as the dependent variable to be used as the basis of comparison because it is easy to document and easy to convert to an economic basis.

For purpose of analysis, the total time required to process any given part was divided into two categories: 1) programming time, and 2) welding time.

Programing time includes table movement and weld sequence planning, table movement programing, actual part programing time and any necessary dry runs or modifying work. Welding time (arc-on-time) was the actual time required to weld excluding interruptions.

Positioning and securing on the table was assumed to be equivalent to the time a manual welder spends positioning and securing the same piece; it may, in reality, be less.

An examination of the programing function revealed an apparent relationship between programming time and the number, type, and orientation of weld segments. The welding time was identified as varying with the number of weld segments and the total weld length.

Two initial tests were designed to begin the development ofa data base from which these apparent relationships could be quantified. The first test was designed to hold the number ofweld segments constant and vary the total weld length. The test consisted of seven similar parts, each with the same number of weld segment (14).

The first part in the series has 6-inch segments and a total weld length of 84". The last part has 24-inch segments and 4 total weld lengths of 336 inches.

The second test was designed to hold the total weld inches constant and vary the number of weld segments. Each of the seven parts had 186 total weld inches; the first part in the series had two segments, the last had forty segments.

All of these parts were fabricated of 1/4" mild steel. They were programmed by the same operator and welded.

Test Results

The following information was recorded.

- Number of segments and total welding inches.
- Time to plan/program table movement and weld sequence.
- Time to program part.
- Time to weld part.
- Total number of points in program.
- Breakdown of different points in program.
- Programming time is proportional to the number of weld segments and the complexity of the segments. It is not significantly affected by the length of the weld segment.
- Complexity of a weld segment is related to how many different orientations the torch must assume to weld the segment. In order of increasing complexity are:
    - Welds with no corners
    - Welds with one corner
    - Welds with two corners
    - Welds with curves
- Programming time is proportionally reduced when more than one segment can be welded in one table position.
- Welding time is related to number of weld segments and total welding inches.

9.4.1 Recommendation

Controlled testing and data collection should continue until simple relationships are confirmed and can be applied to successfully identified prospective parts.

Control Specifications		
Acramattc Computer Control	Version III -	
	English	Metric
Alr Conditioner		
BTU Rating	4000	4220244 J
Running Current	11 AMP	11A
Maximum Ambient	125" F	52°C
Refrigerant	R 22	R 22
It?stalled weight	120 lb	54 kg
VGlt.5ge	115 VAC, 60 Hz single phase	115 VAC, 60 Hz single phese
Power Supply		
Logic Circuit voltzge/AMPS	+5 V DC170	+5 vDc/70
Servo Circuit voltage/AMPS	+12 V13C16	+12 VDC16
Servo Circuit voltage/AMPS	-12 VDC14.O	-12 VDC14.0
Memory Circuit voltage/AMPS	-16.75 VDC15	-16.75 VDCf5
Lamps, relays, robot, tape vollage/AMPS	+24 VDC112	+24 VDC/12
Thermostat (reset temperature)	120° F	49° C
Input requirements	95-130 VAC (RMS) 60+1HZ	95-130 VAC (RMS) 50+1Hz
CRT Module		
Display (ASCII character set upper case only; 12 lines of 32 characters)	5/16"' high x 3/16" wide	8 mm high x 5 mm wide
Input	composite video	composite video
Power requirements	115 VAC, 60 Hz single phase	115 VAC,50HZ . single phase

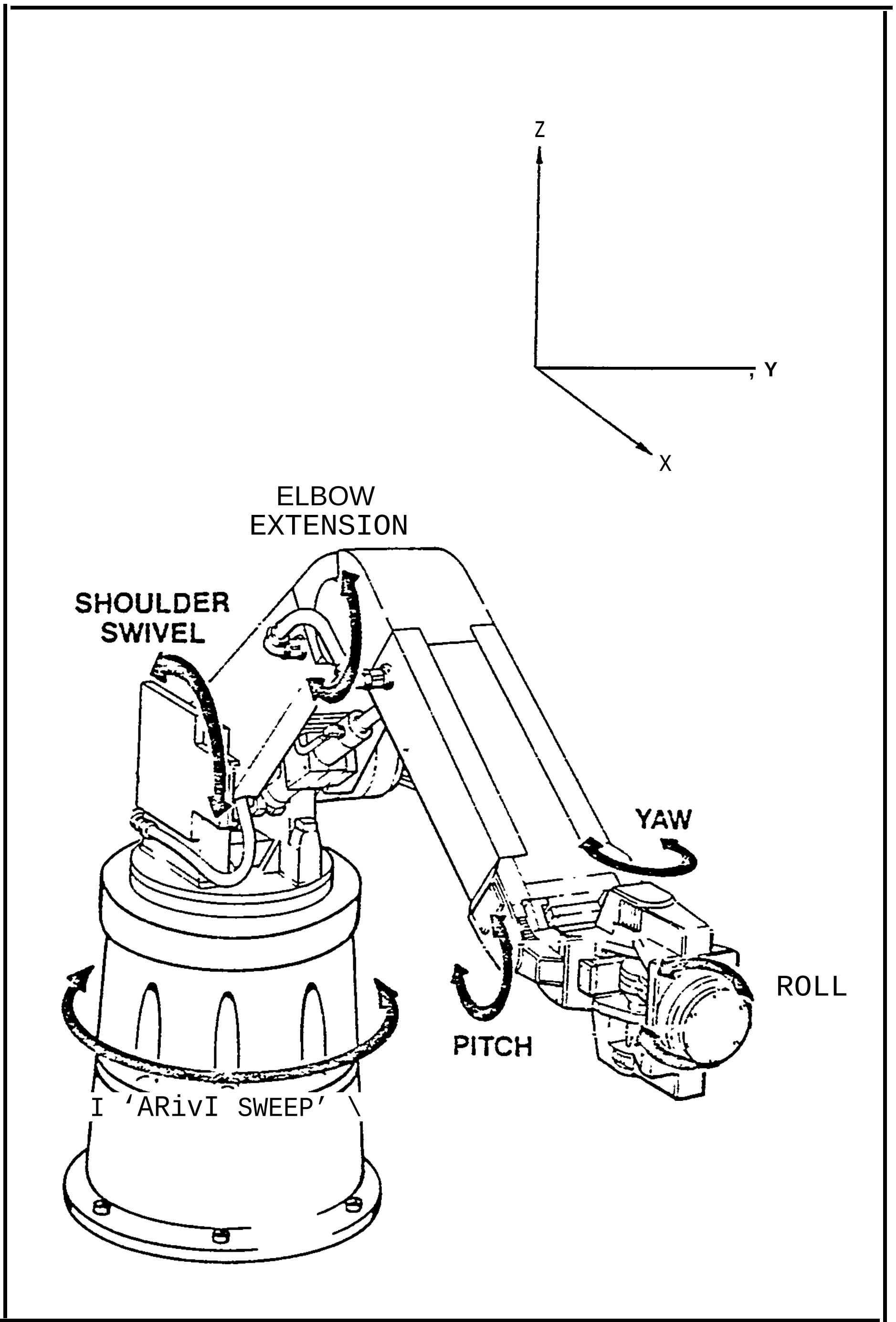
Mechanical Specifications				
T^3 Industrial Robot	Standard T^3 English	Metric	Heavy Duty HT^3 English	Metric
Floor Space/Net weight				
Industrial Robot	9 sq ft /5,100 lb	0.8 sqm/2313 kg	9 sq ft /5625 lb	0.8 sqm/2531 kg
Hydraulic Power Supply	17 sq ft /1200 lb	1.5 sqm/544 kg	17 sq ft /1200 lb	1.5 sqm/544 kg
Electrical Power Unit	3.4 sq ft /700 lb	0.3 sqm/317 kg	3.4 sq ft /700 lb	0.3 sqm/317 kg
Acramatic Computer Control	8.3 sq ft /1100 lb.	0.8 sqm/498 kg	8.3 sq ft /1100 lb	0.8 sqm/498 kg
Load Capacity Load 10" (254mm) from tool mounting plate	100 lb	45 kg	225 lb	102 kg
Velocity (full load)	16 ips	1270 mmps	35 ips	889 mmps
Positioning accuracy Accuracy to any programmed point	±0.050 in	±1.27 mm	±0.050 in	±1.27 mm
Axis Drive	Direct, Electrohydraulic		Direct, Electrohydraulic	
Jointed-arm motions, range				
Maximum horizontal sweep	240°		240°	
Shoulder swivel	120°		90°	
Elbow extension	120°		120°	
Pitch	180°		180°	
Yaw	180°		180°	
Roll	240°		240°	
Axes Displacement				
Base Actuator	20 cu in	328 cm^3	40 cu in	665 cm^3
Shoulder Actuator	40 cu in	665 cm^3	80 cu in	1311 cm^3
Elbow Cylinder	58.9 cu in	965 cm^3	99.5 cu in	1630 cm^3
Pitch Actuator	3.8 cu in	62 cm^3	8 cu in	131 cm^3
Yaw Actuator	1.2 cu in	20 cm^3	3.8 cu in	62 cm^3
Roll Actuator	1.2 cu in	20 cm^3	3.8 cu in	62 cm^3
Power Requirements	460 volts 3 phase, 60 Hz 32 KVA	380 volts 3 phase, 50 Hz 32 KVA	460 volts 3 phase, 60 Hz 32 KVA	380 volts 3 phase, 50 Hz 32 KVA
Environmental temperature	40° to 120°F	5° to 50°C	40° to 120°F	5° to 50°C

EXHIBIT 1B

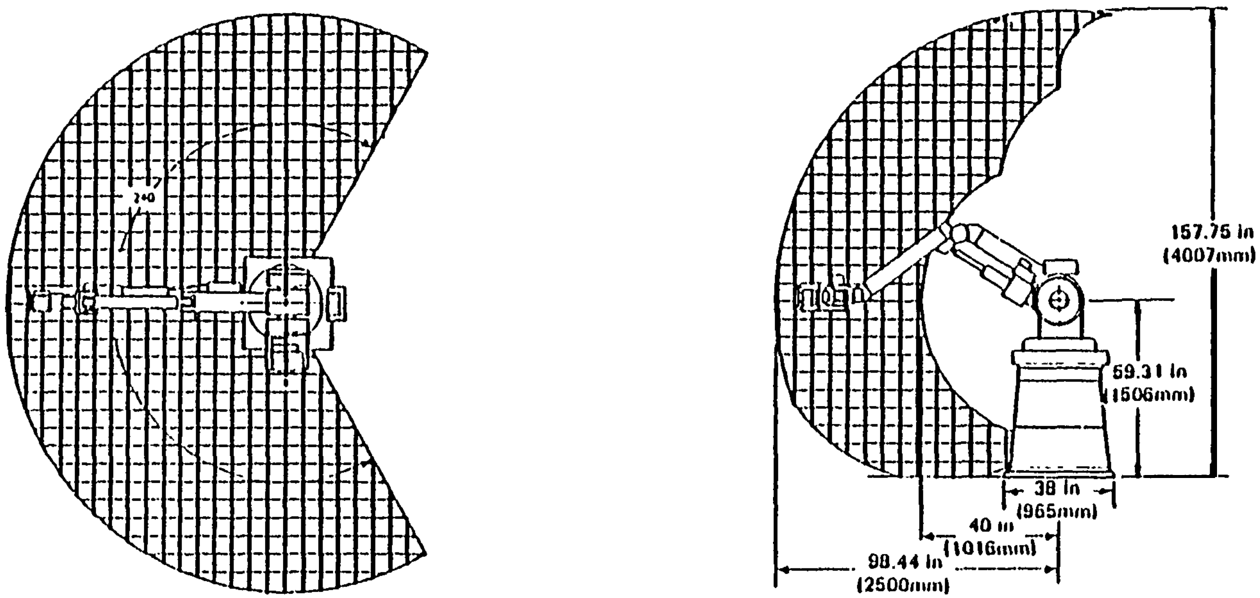
ROBOT MOTION

The motion of the T^3 Industrial Robot is based on three planes. X, Y, and Z.

In and out motion is along the X axis.
Left and right motion is along the Y axis.
Up and down motion is along the Z axis.



OBOT ARM



Note: Standard Interconnection
between units 10ft. (3m)
radius from base of arm.

ROBOT'S WORKING ENVELOPE

EXHIBIT 1D

MEGA-CON 110

fully automatic digital wire feed motor control

HOBART

SOLID STATE

Model 110

The MEGA-CON 110 fully automatic welding system control provides accurate setabiiity of welding parameters of inches per minute wire-feed speed and power source voltage; accurately controls these parameters during welding and allows continuous monitoring of each parameter during the weld cycle. Wire-feed speed may be pre-set accurately to one-inch' per minute and the voltage may be accurately pre-set to.1 volt and the parameters accurately maintained during the welding cycle. Through the use of an accurate digital (3VZ digit) meter, the welding parameters may be monitored continuously during welding, either showing continuously each parameter or alternately cycling every five seconds from voltage to inch per minute indications. Wire-feed speed up to 1000 ipm may be monitored on the digital meter.

WIRE FEED CONTROLS: Wire-feed speed inch per minute is adjustable separately during three cycles of, 1. weld start conditions, 2. weld conditions and 3. crater fill conditions. A retract wire-feed adjustment is also offered to retract the wire back to the contact tip.

VOLTAGE CONTROL: Independent voltage control is provided during the start conditions, weld conditions and crater fill conditions.

TIME FUNCTIONS: Preflow time adjustable from zero cycles to 999 cycles zero seconds to approximately 16.6 seconds. Start time, O-999 cycles. Weld time, O-999 cycles. Crater fill time, O-999 cycles. Burnback time O-999 cycles. Postflow, O-999 cycles. Retract, O-999 cycles. Recycle, O-999 cycles time.

The above voltage, wire-feed speed and timers are enclosed in a separate compatiment with corresponding set switches and is lockable to prevent access to the controls by unauthorized personnel. Also contained in the compartment is a switch for selection of continuous welding or spot conditions, single or recycle operation, a cycle test switch to allow exercising of the program without energizing the power source or feeder.

Additional front panel controls are a main off/on power switch, inch-purge switch, forward/reverse switch, 3VZ digit digital panel meter (.42-inch height digits), welding parameter set-actual switch, voltage-inch per minute selection switch, alternate-fixed indication switch, cycle start button, cycle stop button, ten light emitting diode indicators for appropriate functions, emergency control stop switch, two control fuses.

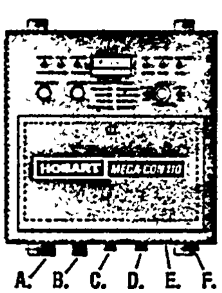
GENERAL CONSTRUCTION–The general construction of the MEGA-CON 110 uses a rugged JIC type enclosure approximately 20%" x 21 Y4" x 9" deep with metallic connector inputs and outputs on the bottom of the control panel.

The MEGA-CON 110 can operate from either a dead-man type operator station or can be operated from the front panel cycle start and stop switches. A remote fixture builder receptacle is provided for interface of fixture controls.

Two plug-in conventional relays are provided for interface to fixture controls and can be actuated anywhere at the beginning of each time cycle. Solid state normally open contact relays may also be provided upon request.

POWER SOURCE COMPATIBILITY
•RC-650-RVS and RCC-650-RVS

AVAILABLE GEAR RATIOS	Wira Feed Spa-d 1PM	CPM
46:1	50-625	127-2095
75:1 Std.	30-500	76-1270
90:1	25-400	63-1016



CABLE SYSTEM (must order separately)

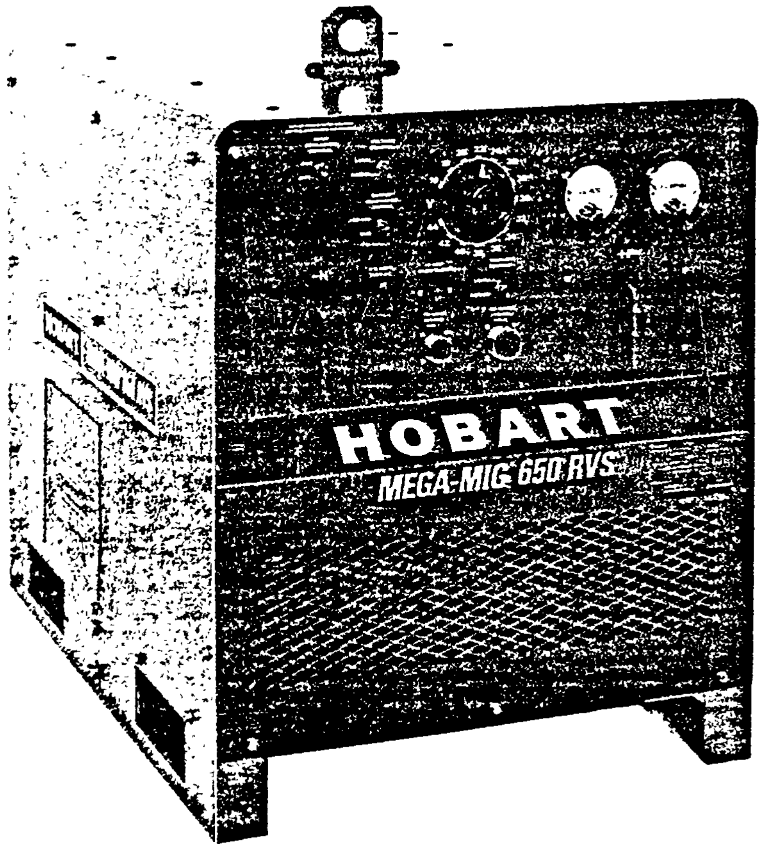
	CABLE LENGTH 15Ft.	16Ft.	25Ft.	50Ft.	75Ft.
A. POWER CABLE-TO POWER SOURCE (1 required)	NA	374767-1	374767-2	374767-3	NA
B. PENDANT ASSEMBLY (option)	374721-1	NA	374721-2	NA	NA
C. FIXTURE CONTROL CABLE (Option)	374766-2	NA	374766-1	374766-3	374766-4
D. VOLTAGE SENSING CABLE-TO WORK (1 required)	374629-2	NA	374629-1	374629-3	374629-4
E. GAS VALVE KIT OR GAS-WATER VALVE KIT (1 kit required) ......Gas Valve Kit	374420-5	NA	374420-3	374420-6	374420-7
Gas-Water Valve Kit (Optional)	374420-8	NA	374420-9	374420-10	374420-11
F. FEEDHEAD CABLE AND FEEDHEAD ASSEMBLY (1 combination required) ......Cable (1 required)	371235-1	NA	371235-2	371235-3	371235-4

FEEDHEAD ASSEMBLY (1 required) — 46:1 gear ratio, 372245-3 — 75:1 gear ratio, 372245-4, 90:1 gear ratio, 372245-5

EXHIBIT 2

MEGA-MIG® 650 RVS

HOBART



Model RC-650-RVS

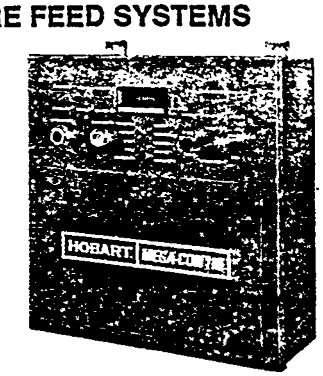
FEATURES:

- Solid State Contactor
- Output Voltage Regulation
- Single W-I-D-E Range
- Solid State Control Circuit Board
- Exceptional Dynamic Response
- Unique, Advanced SCR Design
- Built-in Overload Protection
- Low Voltage On-Off Switch
- Local-Remote Switch
- Designed for Ease of Handling
- Designed for Ease of Maintenance
- Remote or local voltage sensing

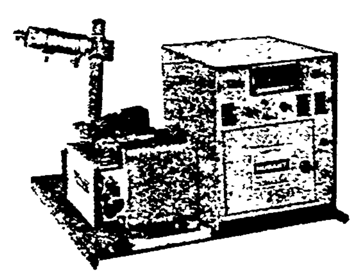
ESSENTIAL DATA

RATING	60 Hz	50 Hz
Welding Amps, DC	650	650
Volts, DC	44	44
Duty Cycle %	100	100
WELDING VOLTAGE AND CURRENT RANGE		
Minimum	100 A @ 18V	100 A @ 18V
Maximum	800 A @ 40V	800 A @ 40V
Voltage Range Step	1	1
INPUT RATING		
Line Voltage	200/230/460/575	220/380/415/500
Phase	3	3
Hertz	60	50
Line Amps @ Rated Load	122/106/53/42.5	110/64/59/49
Line Amps @ No Load	7.5/6.5/3.25/2.6	7.8/4.5/4.2/3.5
KVA @ Rated Load	42.2	42.2
KVA @ No Load	2.8	2.8
KW @ Rated Load	33.0	33.0
KW @ No Load	1.5	1.5
Power Factor @ Rated Load	.78	.78
Eff. @ Rated Load	87%	87%
Auxiliary Power	.5 KW	.5 KW
Fuse Size (Amps)	200/175/80/60	175/100/90/75
Power Input Cable (Gauge)		
Single conductors in free air	3/4/8/8	3/8/8/8
Not more than three conductors in raceway, cable or earth	2/2/6/8	2/6/6/6

DESIGNED FOR USE WITH DIGITAL WIRE FEED SYSTEMS



MEGA-CON 110 (Factory Direct Sales Only)



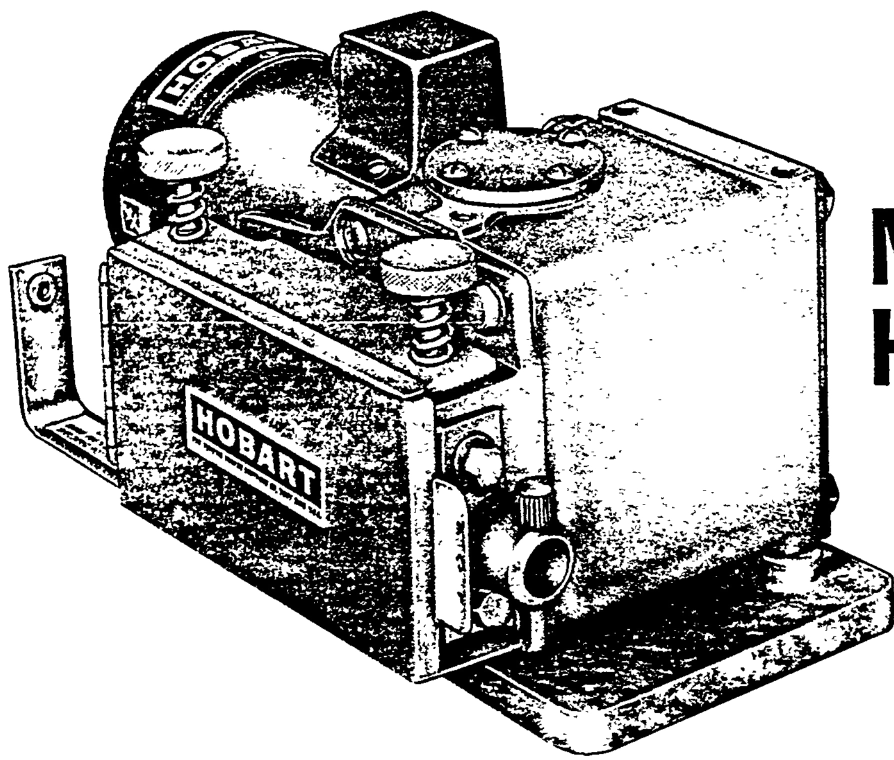
MEGA-CON DS and MEGA-CON SS (See Data Sheet 554-E)

EXHIBIT 3

Hobart solid state wire drive feedheads

HOBART

SOLID STATE



Model H4S

This Solid State controlled feed motor is a part of Hobart Modular Wire Feed System. This model features a tachometer feed back system for precise speed control. Control panels used include: 101, 105, Mega Con 110 and 70L feeder controls.

Standard Hobart auto-torches or semiautomatic guns can be used to fit your application.

Create your custom welding system using this feed head, other components as listed below, and related accessories available from Hobart.

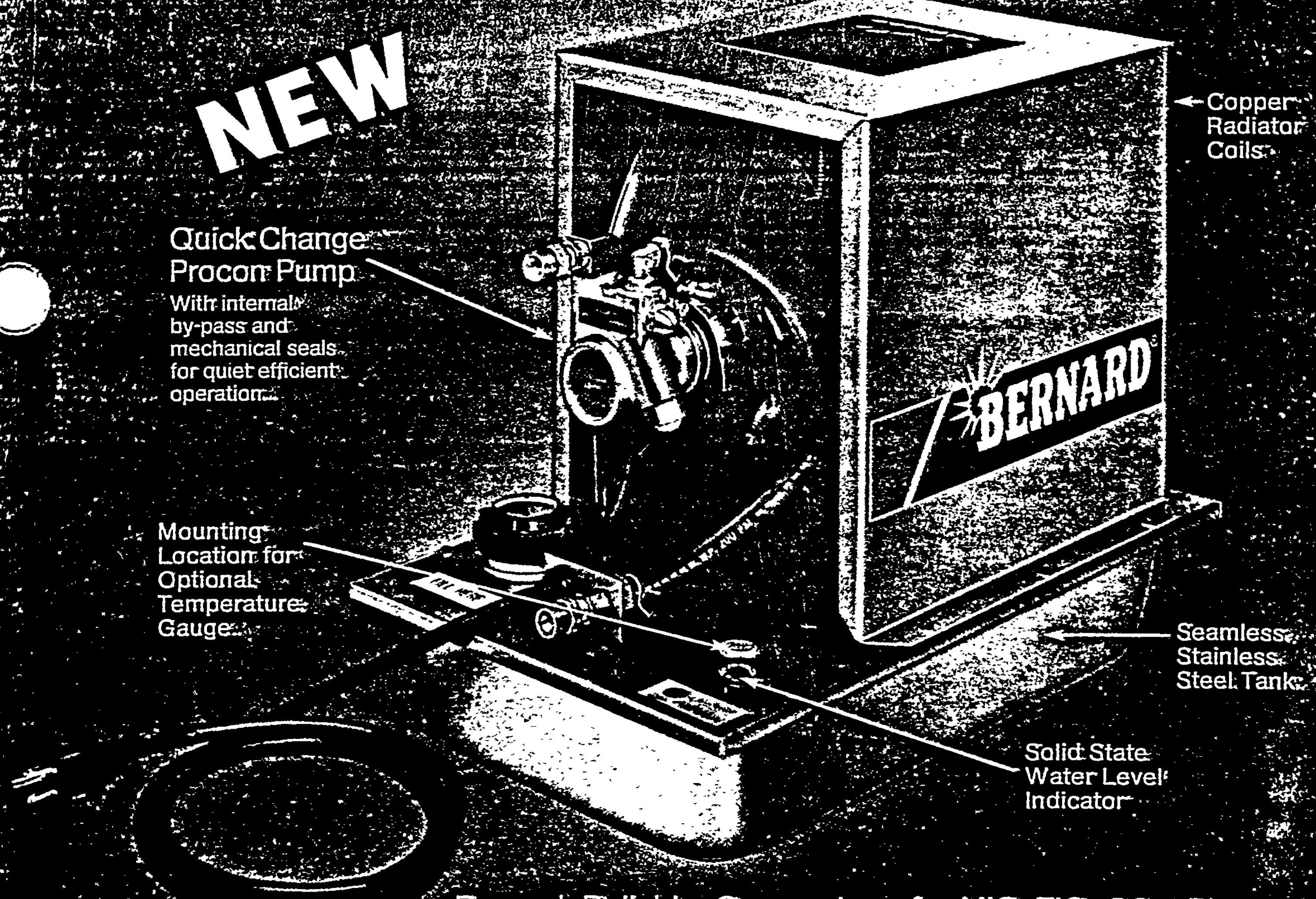
For specifications and mounting dimensions, see back.

You need each of the following components to complete your wire feed system

CONTROL PANEL See Data Sheets 553-B, 553-BA, 553-C	**MOTOR AND GEARBOX**	**TORCH** See Data Sheet 553-E OR **SEMI-AUTOMATIC GUN** See Data Sheets 562-A, 562-B, 562-E, 563-E	**WIRE FACILITIES** See Data Sheet 553-F	**CONSTANT VOLTAGE POWER SUPPLY** See Data Sheets 542-B, 543-E, 544-D, 547-B

EXHIBIT 4

3500SS Stainless Steel Water Cooler by Bernard



Rugged, Reliable, Compact .... for MIG, TIG, CO_2, Plasma, Resistance and Electro-Slag Type Welding Equipment.

BERNARD

EXHIBIT 5

BERNARD®

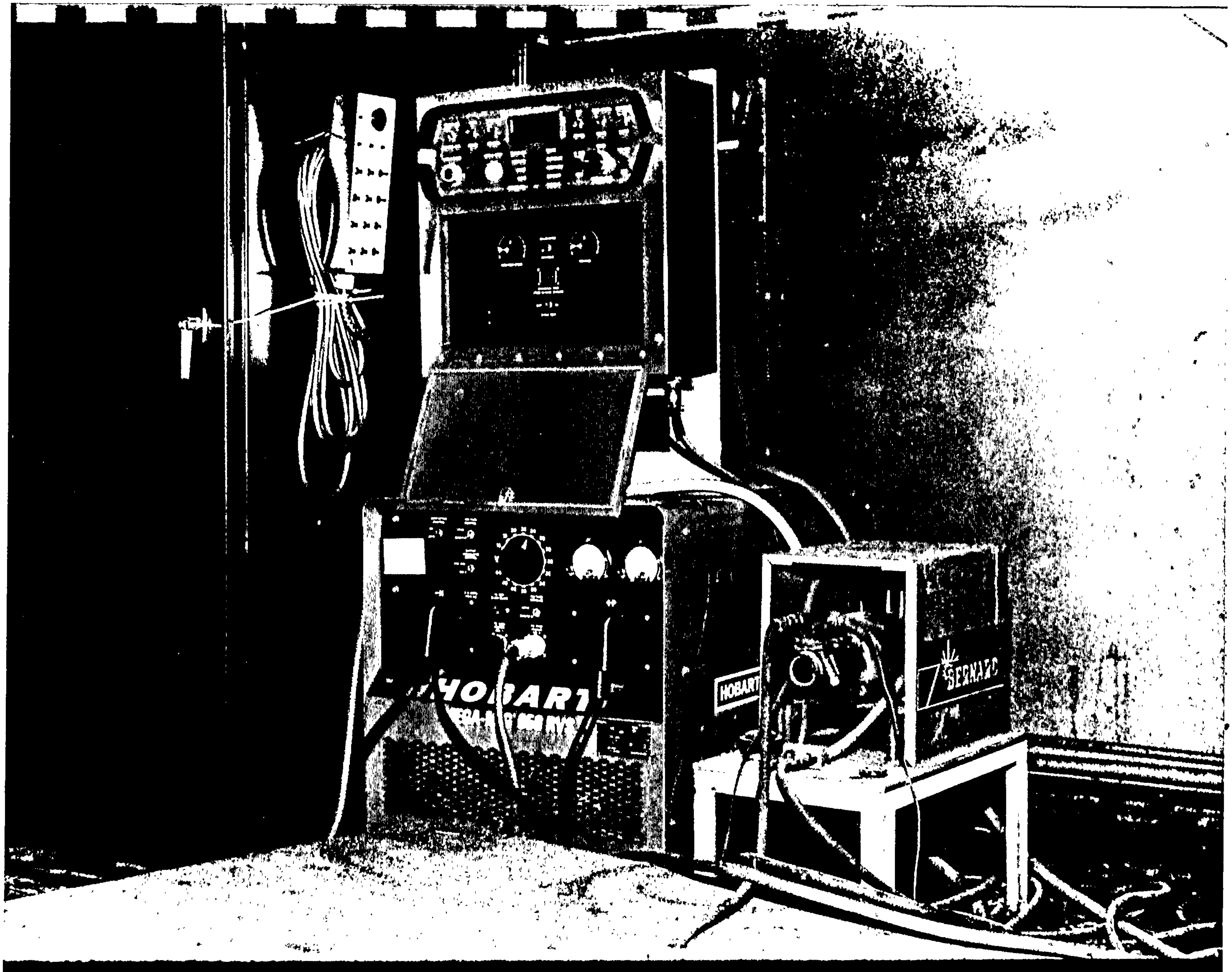
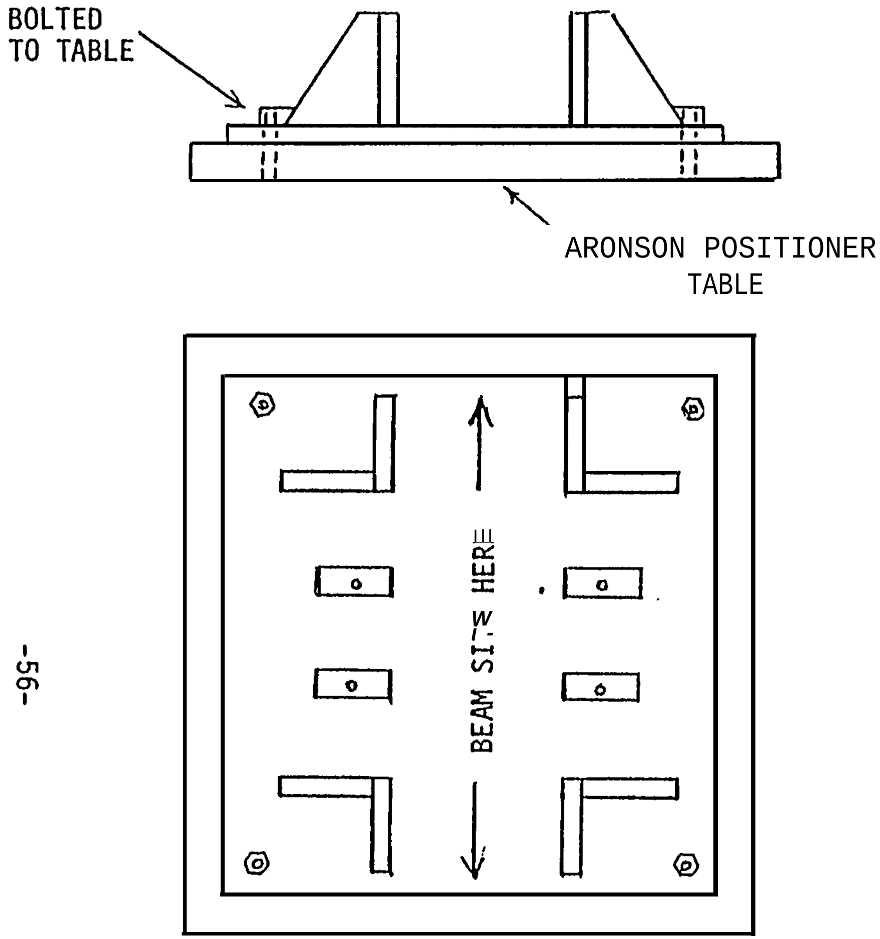
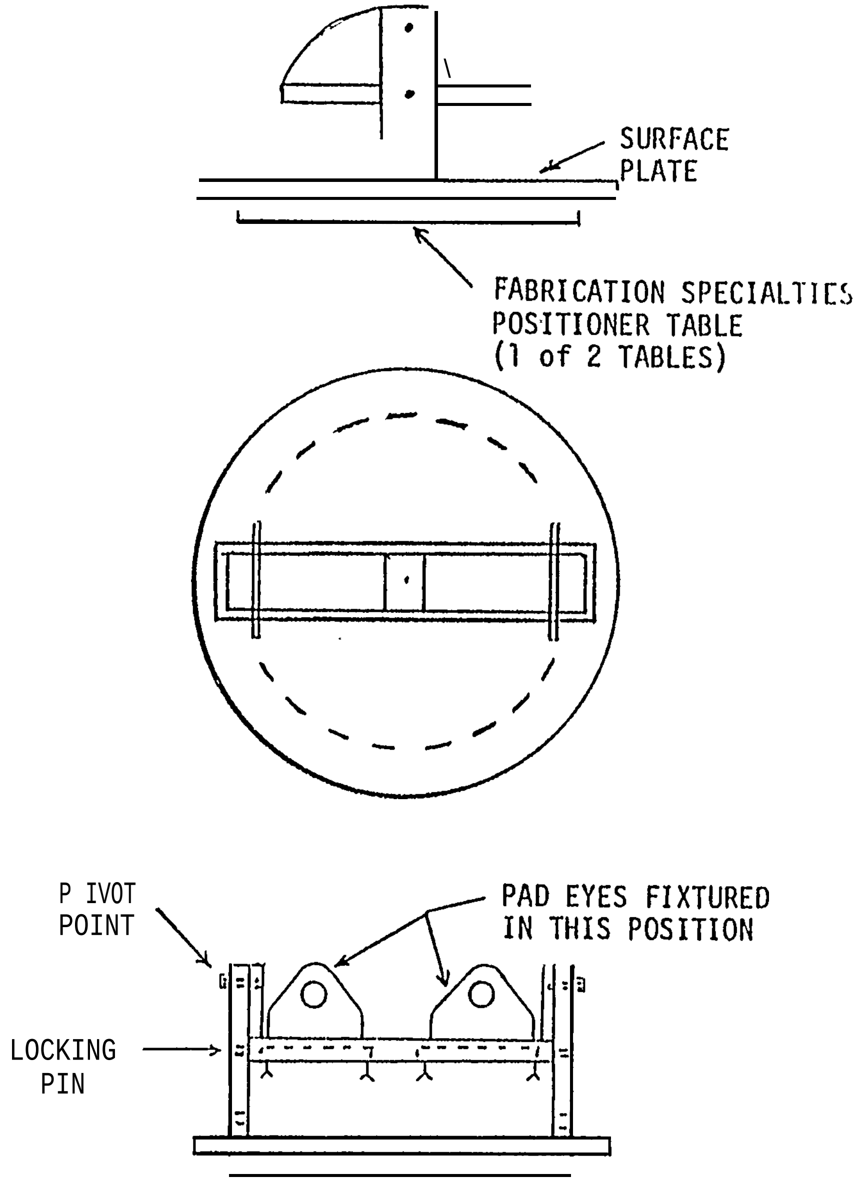


EXHIBIT 6

PART FIXTURING



BEAM JIG FIXTURED ON
ARONSON POSITIONER



PAD EYE JIG FIXTURED
ON FABRICATION SPECIALTIES
DUAL POSITIONER

EXHIBIT 7A

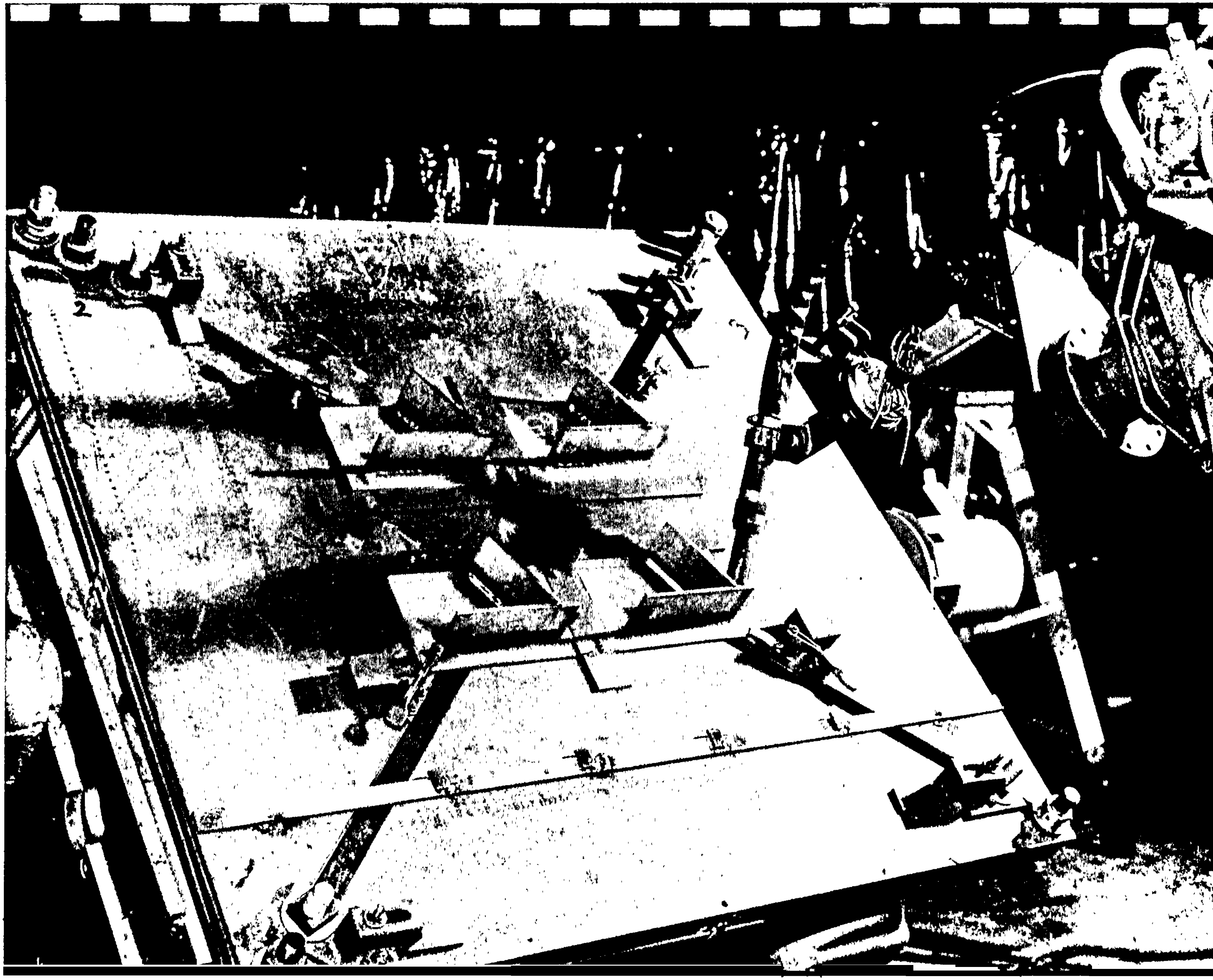
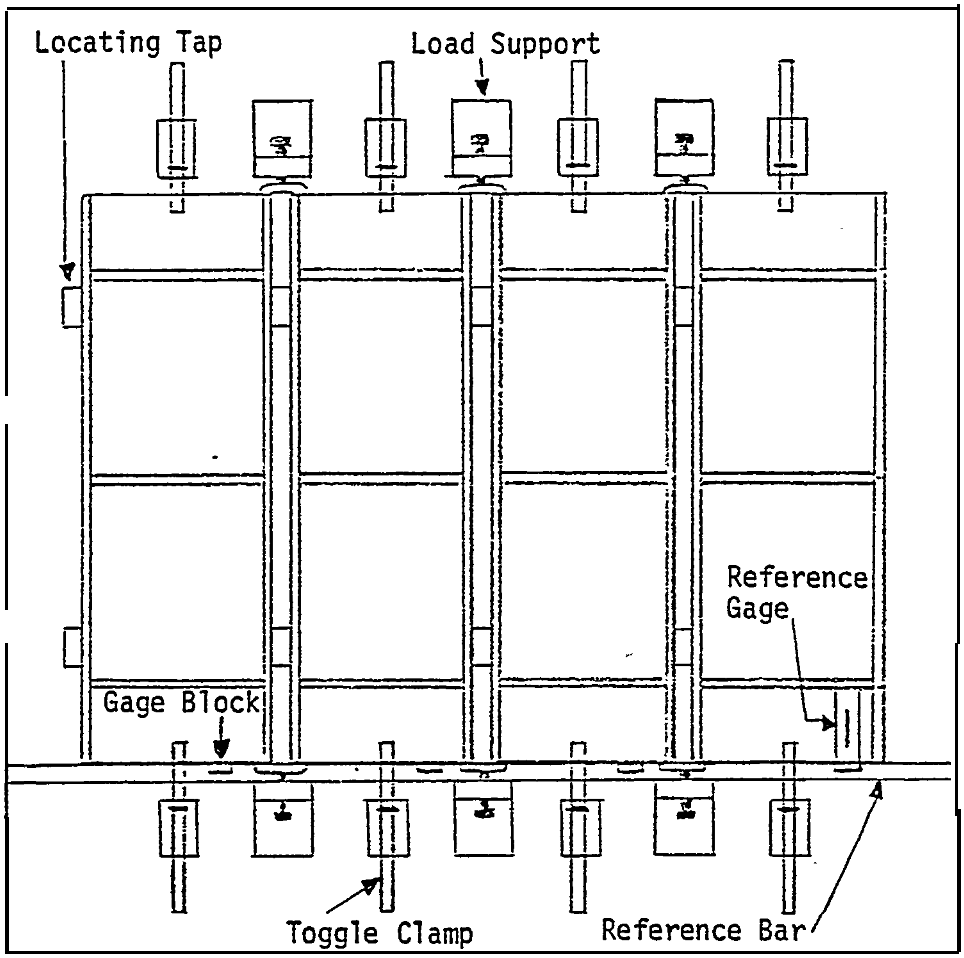


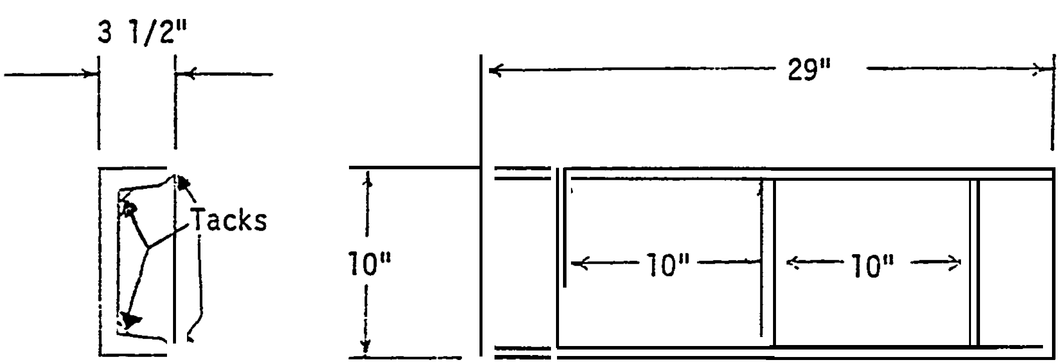
EXHIBIT 7B

WHEEL ASSEMBLY SUPPORT
TACKING & FIXTURING DETAILS



Top View of Posio tioning Tab le

FIXTURE DEVICE

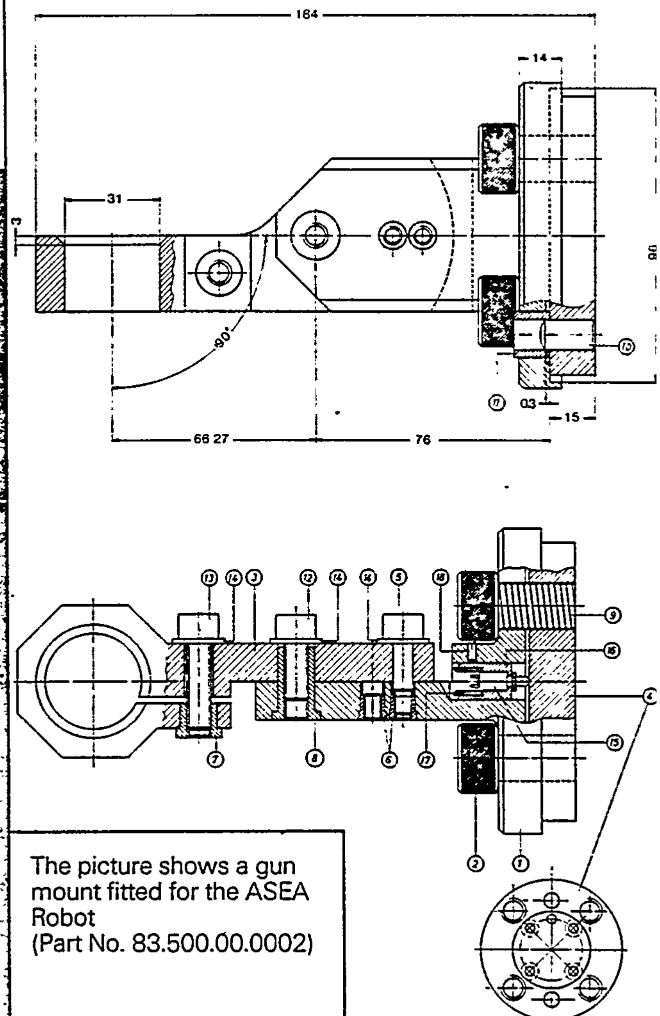


3/8" x3" x9" Stiffener

TACKING DETAIL OF WORKPIECE

EXHIBIT 8

Binzel "Safety" Gun Mount For Welding Robot



The picture shows a gun mount fitted for the ASEA Robot
(Part No. 83.500.00.0002)

GUN MOUNT

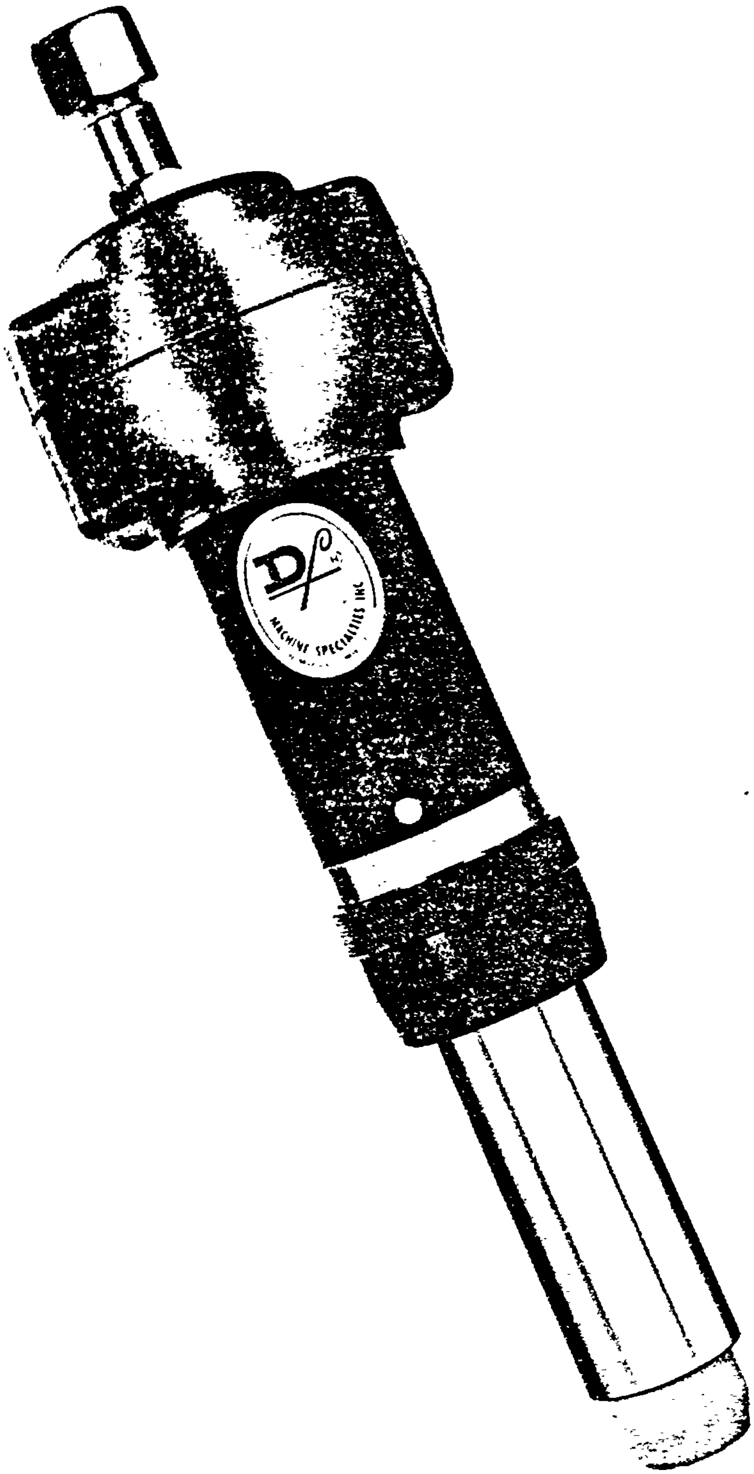
- Integrated emergency switch and safety mount
- Four position adjustment
- By exchanging the base plate (iem No. 4), the gun mount can be fitted to most Robot makes.
- Light weight, approx. 1¾ lbs.
- Very close manufacturing tolerances.
- After a light collision the auto snap-back action realigns the gun or the emergency switch stops the process.

No.	Part No.	Quantity	Description
1	83.500.02.0001	1	Base Plate
2	83.500.02.0008	4	Knurled Nut
3	83.500.02.0003	1	Swivel Arm w/Barrel Receptacle
4	83.500.02.0002	1	Robot Mounting Plate
5	83.500.02.0009	1	Angle Adjustment Screw
6	83.500.02.0006	2	Nut Insert, Small
7	83.500.02.0007	1	Nut Insert, Medium
8	83.500.02.0005	1	Nut Insert, Long
9	83.500.02.0004	4	Tension Spring
10	DIN 6325	2	Guide Pin
11	DIN 179	2	Guide Insert
12	DIN 912	1	Allen Screw
13	DIN 912	1	Allen Screw, Long
14	DIN 125	3	Washer
15	83.500.02.0010	1	Safety Switch
16	83.500.02.0011	1	Switch Sleeve
17	83.500.02.0012	1	Insulating Sleeve
18		1	Set Screw

EXHIBIT 9

MACHINE SPECIALTIES INC.

MECHANIZED and ROBOTIC WELDING PRODUCTS



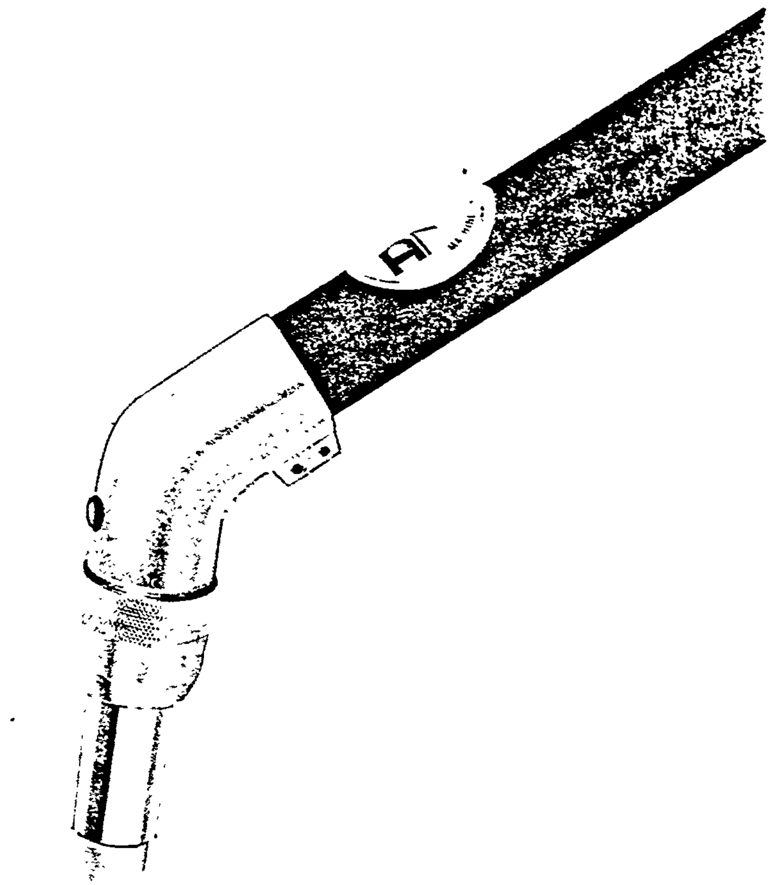


EXHIBIT 10

The increased utilization of robotic welding systems has created a demand for welding tools of the highest quality and durability. For several years, D/F automatic welding barrels have been used extensively on automatic "MlG" welding applications. This experience. coupled with patented design features unavailable on any other competitive equipment, has made D/F welding tools the most advanced "MIG" welding guns and barrels for mechanized and robotic applications. This brochure was prepared as an aid in selecting the proper welding tool for a given robotic or automatic welding application.

WATER COOLED "MIG" GUNS–REMOTE MOUNT

The durable HTCINCC curved gun assemblies provide good accessibility to the weld joint because of the compact frontal area and curved design. The curved gun assemblies also utilize the same forward nozzle assemblies and features of the stan. dard straight barrel assemblies. This allows a versatile and low inventory of parts due to the interchangeability of the welding tools.

MODEL EXPLANATION

HTC-Heavy-ctuty, Threaded current tip, Curved gun assembly
NCC-Norrnal duty, Collet action (slip-in current tip), Curved gun assembly

FEATURES

- **Accessibility—three nozzle lengths in.line services**
- **Flexibility-lightweight flexible service lines; swivel casing**
- **Durability—closed water system protective sheath**

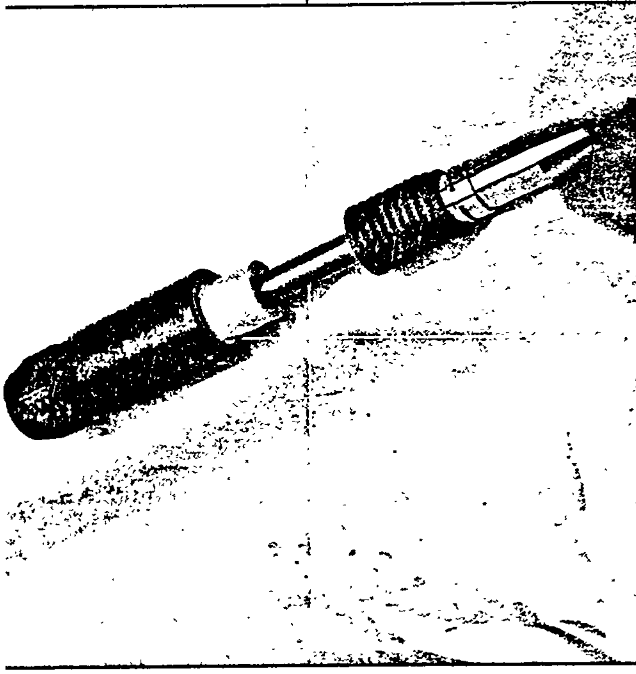
HTCfNCC SERIES SPECIFICATIONS

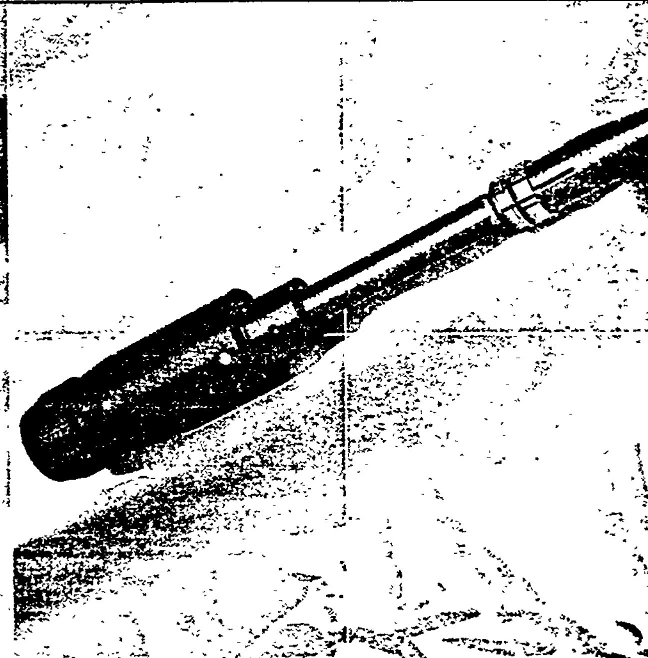
Current Capacity
HTC Series ....5Wamp continuous duty
NCC Series ....450 ampcontinuous duty
Gun Dimensions
Overall length with3" nozzle ....13.zjo"
4" nozzle ....14.750"
5" nozzle ....15.750"
Gun Angle—55 • curved elbow diameter of handle ....1.500"
Nozzle to elbow clearance with 3" nozzle (approx.) ....6.250"
Recommended Wire Range
HTC ....03~"..062" Hard
5164"-7164"" Cored
NCC ....030'"..062" Hard
3/64".3/32'" Aluminum
Weight (approx.)—without services.. ....2.21bs.
~ling RquirW .... Minimum 5pint~minute

ORDERING INFORMATION

Description	Code No. for Selection of Available Lengths		
	6 Ft.	7 Ft.	8 Ft.
MODEL HTC (Threaded TID)			
Water Coold" Nozzle Option			
Short 3" Water Cooled Nozzle	11435	11674	11408
Inter. 4" Water Cooled Nozzle	11436	11675	11409
Long 5' Water Cooled Nozzle	11437	11676	d 11410
MODEL NCC (Slip-in Tip)			
Water Cooled Nozzle Option			
Short 3" Water Cooled Nozzle	11432	11678	11405
Inter. 4" Water Cooled Nozzle	11433	11679	11406
Long 5" Water Cooled Nozzle	11434	11680	11407

Binzel Robo$^{T.M.}$ 25 / Robo$^{T.M.}$ 450





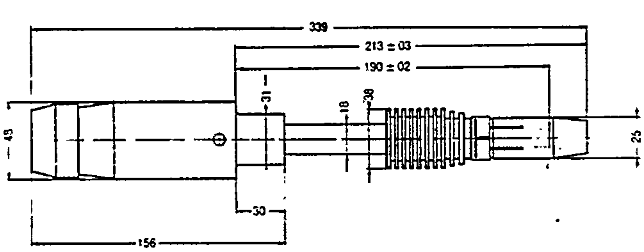
Specifications:

Max. Current:	280 A CO_2 200 A, mixed gases
Duty cycle:	80%
Coolant:	Air
Wire Sizes:	0.8 (.030"); 0.9 (.035'); 1.0 (.040"); 1.2 (.045")
Cleaning Media:	Compressed air, with or without anti-spatter spray dependent upon unit.
Cable Assembly:	Bikox®. Unitized with KZ2 central adaptor block 3 m (10 ft.) long.

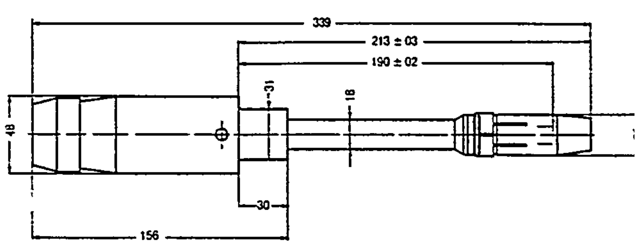
Specifications:

Max. Current:	500 A CO_2 450 A, mixed gases
Duty Cycle:	100%
Coolant:	Water
Wire Sizes:	0.8 (.030"); 0.9 (.035"); 1.0 (.040"); 1.2 (.045"); 1.6 (1/16")
Cleaning Media:	Compressed air, with or without anti-spatter spray dependent upon units.
Cable Assembly:	Composite cable with WZ2 central adaptor block; 3 m (10 ft.) long.

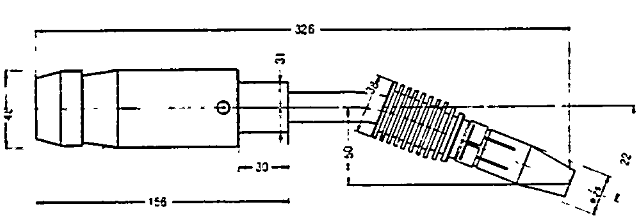
Robot Gun RoBo 25, Standard



Robot Gun RoBo 450, Standard



Robot Gun RoBo 25, Swan neck 22°



Robot Gun RoBo 450, Swan neck 22°

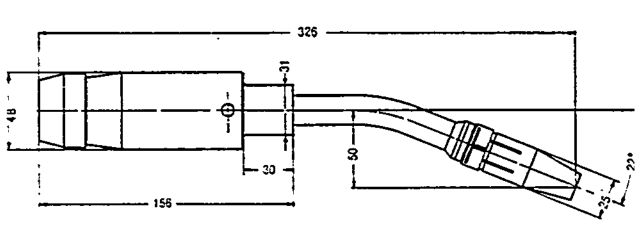
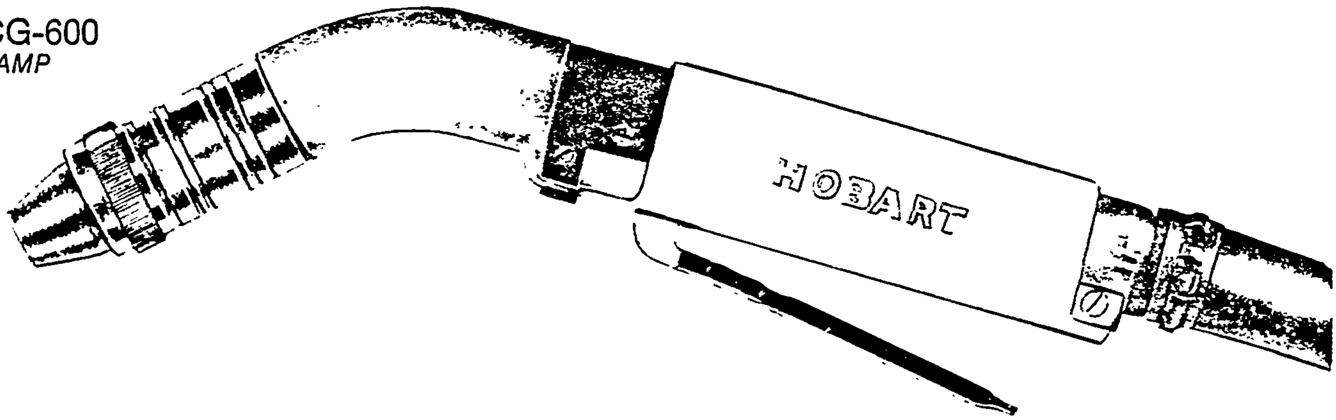


EXHIBIT 11

WCG-600
600 AMP



WCG-600

Rating	AMPS	DUTY CYCLE	GAS SHIELD
	600	100%	CO_2
	500	100%	Mixed Gases

WIRE SIZES .035", .045", 1/16", 3/32" Hard; 3/64", 1/16", 3/32" Soft; 5/64", 3/32" Flux Cored

CABLE 600 Amp. Composite 10, 12 or 15 ft. Water Cooled or Air Cooled Power Cable

TIP Slip-in 5/16" O.D., .045" Std.

NOZZLE Heavy Duty with Retainer Fitting

Water Cooled Gun Tube is in direct contact with the Tip Nut and Tip. The water jacket is in direct contact with the nozzle.

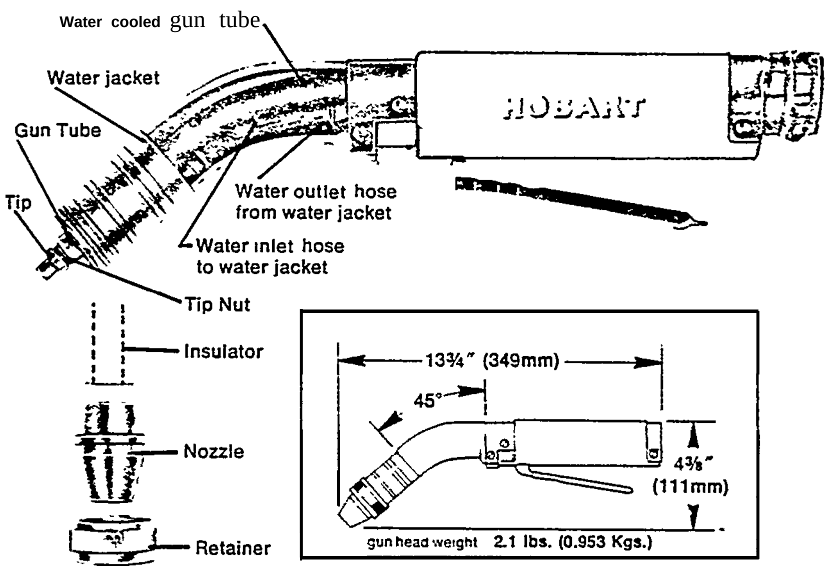
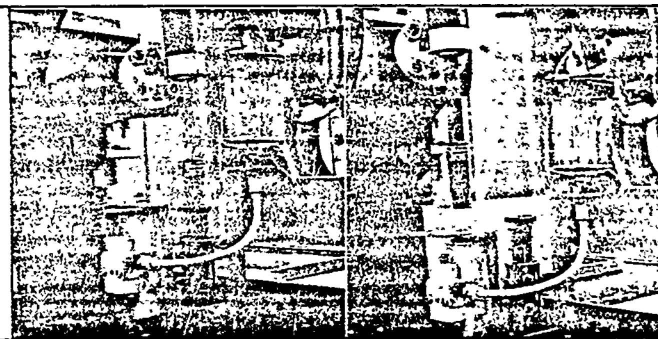
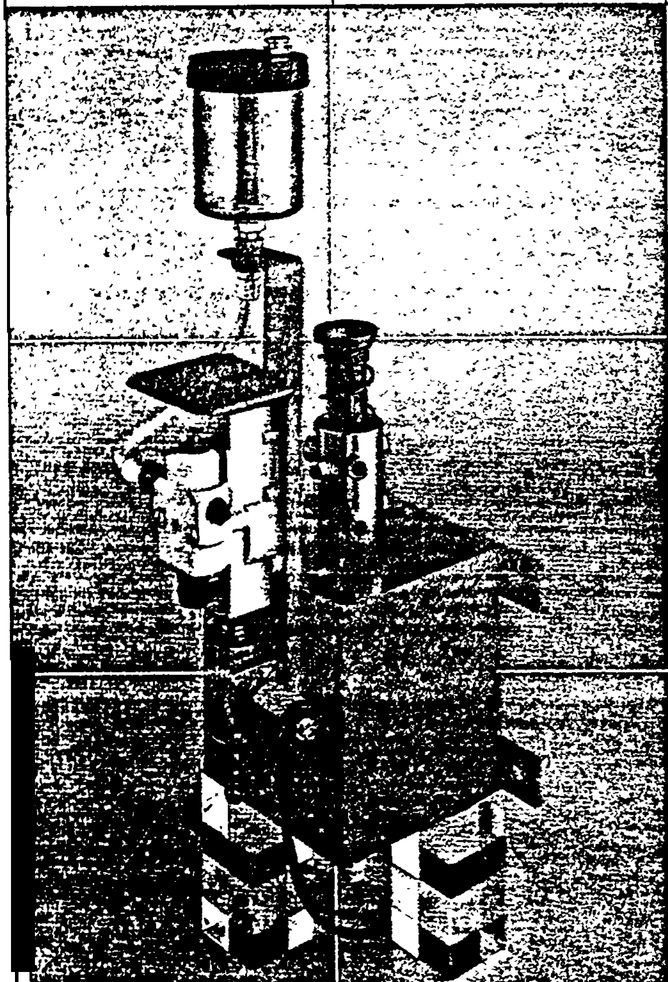
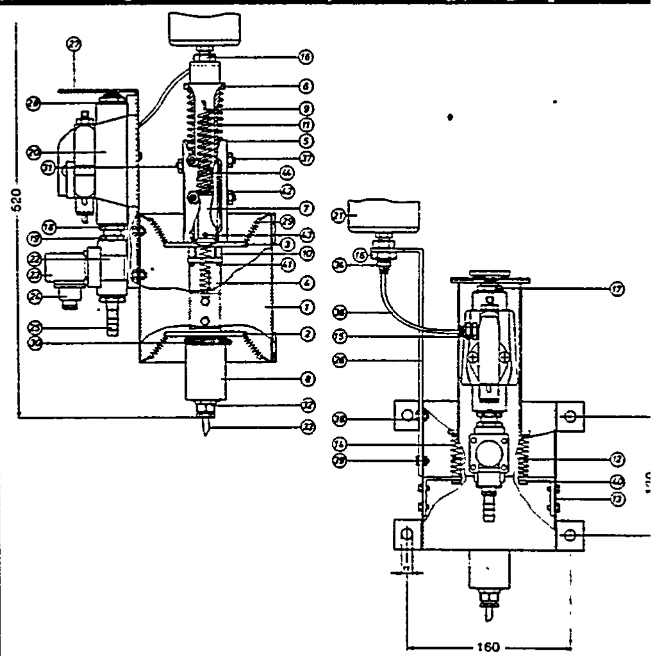


EXHIBIT 12

Binzel Nozzle Cleaner for Robotic Welding







"Performance Kit" (cleaning device with nozzle reamer and spraying unit)

The unit pictured is set for a ⅝" nozzle I.D. By exchanging the reamer spring and retainer stud, the unit can be converted to any size nozzle I.D. ⅝" and ½" nozzle bore sizes are standard.

Fully automated

The unit should be installed within the operating reach of the Robot. The rotating direction of the reamer spring is clockwise. Nozzle I.D. and reamer spring have to match. The spring has to be adjusted so that the nozzle insulator will not be damaged when operating. The unit, when delivered, is adjusted for the standard 2¾" length gas nozzle. The reamer spring is powered by a 24V DC motor. The spatter ejection takes place between the reaming and spraying cycle. The spraying of the nozzle should be direct and at an approximate distance of 1". The "PERFORMANCE KIT" forces pure compressed air through the "SWAN NECK", preventing an eventual spatter clogging.

No.	Part No.	Quantity	Description
1	83.001.01.0001	1	Housing Complete
2	83.001.02.0003	1	Motor Mounting Bracket
3	83.001.02.0005	1	Reamer Mounting Bracket
4	080.02.031	1	Reamer Motor
5	83.001.02.0001	1	Guide Barrel
6	83.001.02.0002	1	Nozzle Rest
7	83.001.02.0006	1	Spring Holder
8	83.001.02.0004	1	Motor Cover
9	83.001.02.0028	1	Reamer Spring
10	83.001.02.0008	4	Spacer
11	83.001.02.0031	1	Counter Spring
12	83.001.02.0013	2	Spring Guide
13	83.001.02.0011	2	Spring Guide Bracket
14	83.001.02.0030	2	Separation Spring
15	83.001.02.0007	1	Hose Fitting, Oiler
16	83.001.02.0010	1	Lock Nut
17	83.001.02.0012	1	Ejection Nozzle
18	83.001.02.0014	1	Cuppling, Solenoid
19	83.001.02.0015	1	Lock Nut
20	83.001.02.0017	1	Single Point Lubricator
21	83.001.02.0018	1	10 oz. Reservoir
22	83.001.02.0019	1	Solenoid Valve Base
23	83.001.02.0020	1	Solenoid Valve Top
24	83.001.02.0021	1	Electrical Connector
25	83.200.02.0003	1	Compressed Air Inlet Fitting
26	83.001.02.0024	1	Reservoir Mounting Bracket
27	83.001.02.0025	1	Spray Deflector
28	83.001.02.0022	1	Washer
29	83.001.02.0029	8	Centèr Spring
30	169.09.052	1	Hose Clamp
31	83.001.02.0009	2	Adjustment Screws
32	83.001.02.0032	1	Plug for Motor
33	83.001.02.0033	1	Power Cord
34	83.001.02.0034	1	Hose Fitting, Reservoir
35	500.02.050	1	Lock Nut
36	83.001.02.0035	1	Hose
37	83.001.02.0036	6	Lock Nut
38	DIN 933	8	Hex Bolt
39	DIN 934	4	Hex Nut
40	DIN 912	2	Stud
41	DIN 912	4	Allen Screw
42	DIN 934	7	Lock Nut
43	DIN 916	3	Set Screw
44	DIN 963	2	Retainer Screw

EXHIBIT 13

EXHIBIT 14A

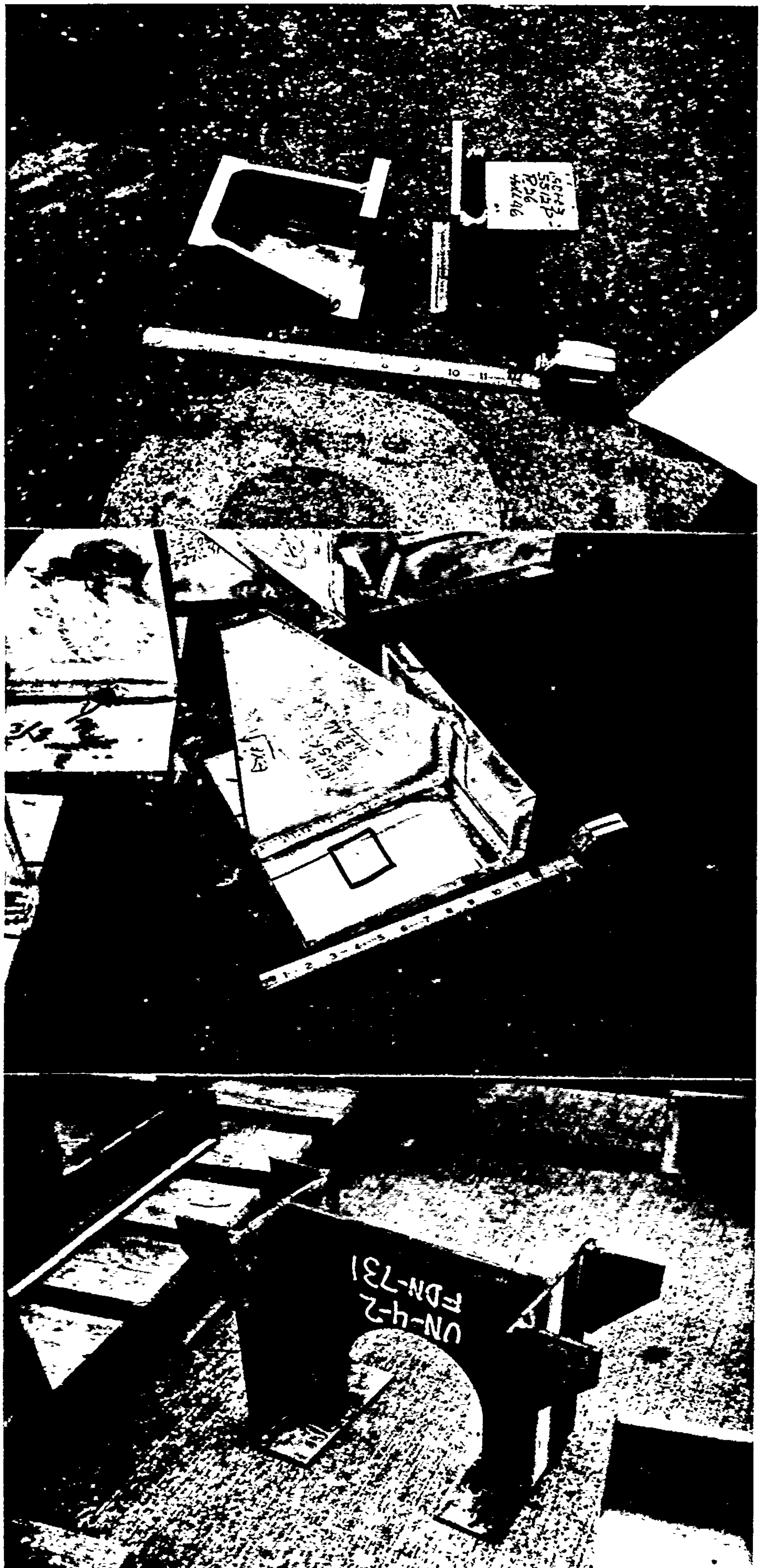


EXHIBIT 14B

TODD PACIFIC SHIPYARDS CORPORATION LOS ANGELES DIVISION	PRODUCTION WELDING PROCEDURE	No: 55-3 Rev: 0 Issued 10-12-82 Page 1 of 3

DESCRIPTION: AWS D1.1 FILLET WELDING ON LOW & MEDIUM CARBON STEELS, AUTOMATIC

WELDER QUALIF.	AWS D1.1, Section 5, Part D	*PROCEDURE QUALIF. STD.*	AWS D1.1 - Prequalified
BASE METALS	Groups I & II, ASTM A36 (Typ.)	*PROCESS*	Flux Cored Arc Welding, Automatic (FCAW)
SPEC./TYPE FILLER METAL	AWS A5.20 E71T-1	*POWER SOURCE POLARITY*	DC Electrode Positive Reverse Polarity
POSITION OF WELD	Flat, Horizontal, Vertical	*FLUX/INERT GAS WITH FLOW RATE*	CO_2, 45 cfh
JOINT PREPARATION & SIDE NUMBER	Welded surface is to be free from loose or thick scale, slag, rust, moisture, grease and other foreign material including primer. Single or multiple pass fillets may be used within the limits specified herein.		
INTERPASS CLEANING	Remove slag and foreign material from joint.		
REPAIRS	Remove all defects before welding of next bead. Chip, grind or arc gouge.		
PREHEAT TEMPERATURE	70°F minimum		
POSTHEAT TEMPERATURE	None	*INTERPASS TEMPERATURE*	70°F minimum
HEAT TREATMENT	None	*ELECTRODE CONTROL*	TPLA Weld. Proc. Man. N-2, Sec. 6-2
WELD TECHNIQUE	0-15° Push Angle. Do not weld in drafts greater than 5 mph.		

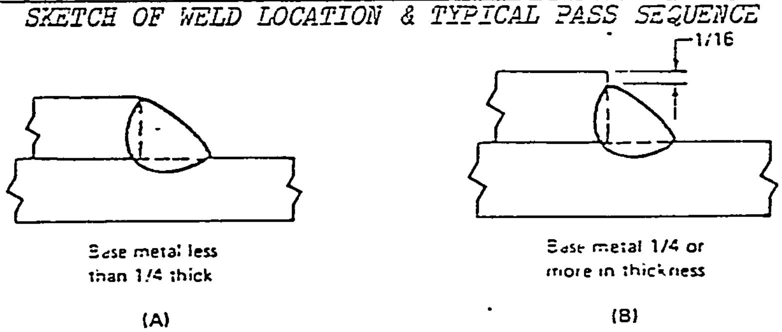
PASS NUMBER	*FILLER METAL SIZE*	*AMPERAGE RANGE*	*ARC VOLTAGE RANGE*	*POSITION*
	.052	175-200	23-25	V-up
Repair only	.052	175-200	23-25	V-down
	.052	275-350	22-29	F, H
	1/16	175-250	22-25	V-up
Repair only	1/16	175-250	22-25	V-down
	1/16	150-400	22-32	F, H

NOTES:

1) Maintain a 3/4"-1" contact tube to work distance.

JOINT DESIGN: Fillet *SPEC.:* AWS D1.1-82 *THICK. RANGE QUAL.:* Unlimited

SKETCH OF WELD LOCATION & TYPICAL PASS SEQUENCE



Maximum size of fillet weld along edges

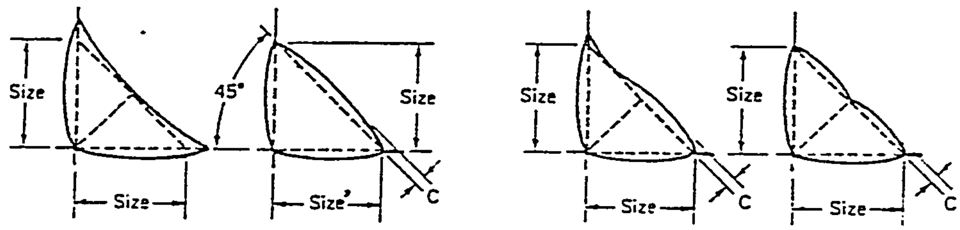
APPROVAL: TPSLA Weld. Engr. Dept. John P. Macie

Customer

EXHIBIT 15 - Weld Parameters

TODD PACIFIC SHIPYARDS CORPORATION LOS ANGELES DIVISION	PRODUCTION WELDING PROCEDURE	No: 55-3 Rev: 0 Issued 10-12-82 Page 2 of 3

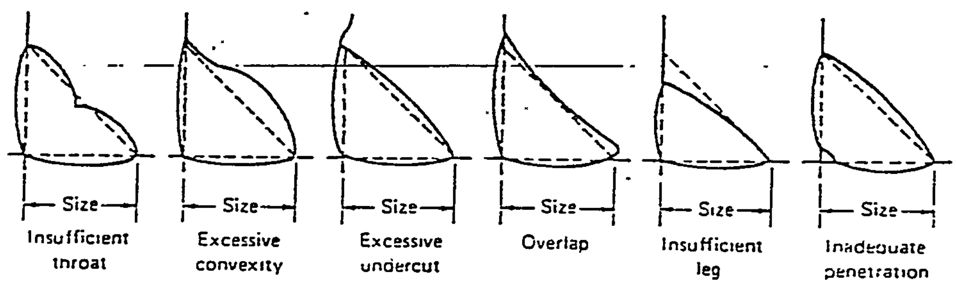
DESCRIPTION: AWS D1.1 FILLET WELDING ON LOW & MEDIUM CARBON STEELS, AUTOMATIC



Note: Convexity, C, of a weld or individual surface bead shall not exceed 0.07 times the actual face width of the weld or individual bead, respectively, plus 0.06 in. (1.5 mm).

Desirable fillet weld profiles

Acceptable fillet weld profiles



Unacceptable fillet weld profiles

ACCEPTABLE AND UNACCEPTABLE WELD PROFILES

APPROVAL: TPSLA Weld. Engr. Dept. ____________

Customer

DESCRIPTION: AWS D1.1 FILLET WELDING ON LOW & MEDIUM CARBON STEELS, AUTOMATIC

Minimum Fillet Weld Size For Prequalified Joints

Base metal thickness of thicker part jointed (T) in.	Minimum size of fillet weld* in.	
T ≤ 1/4	1/8**	Single pass welds must be used
1/4 < T ≤ 1/2	3/16	
1/2 < T ≤ 3/4	1/4	
3/4 < T	5/16	

*Except that the weld size need not exceed the thickness of the thinner part joined. For this exception, particular care should be taken to provide sufficient preheat to ensure weld soundness.
**Minimum size for bridge applications is 3/16 in.

Maximum Electrode Diameter and Fillet Weld Size

Max. Electrode Diameter in.	Welding Position*	Max. Size Of Fillet Weld** in.	Welding Position*
5/32	F, H	1/2	F, V
3/32	V	3/8	H
5/64	OH	5/16	OH

*Flat (F), Vertical (V), Horizontal (H), Overhead (OH).
**Maximum size of any one pass.

APPROVAL: TPSLA Weld. Engr. Dept.
Customer

EXHIBIT 15

Weld Parameters

TODD SHIPYARDS CORPORATION LOS ANGELES DIVISION	PRODUCTION WELDING PROCEDURE	No: 571 Rev: 1-3-77 Issued 4-26-67 Page 1 of 2

DESCRIPTION: GMAW SOLID WIRE FILLET WELDED T JOINT ON ALUMINUM ALLOY

WELDER QUALIF.	MIL-STD-248	*PROCEDURE QUALIF. STD.*	MIL-STD-248 MIL-STD-278 NAVSHIPS 0900-000-1000 (1)
BASE METALS	QQ-A-250/9 Type 5456 GROUP S-25	*PROCESS*	INERT GAS SHIELDED METAL ARC
SPEC./TYPE FILLER METAL	MIL-E-16053 MIL-5556 GROUP A-22B	*POWER SOURCE POLARITY*	DC ELECTRODE POSITIVE REVERSE POLARITY
POSITION OF WELD	VERTICAL UP AND OVERHEAD	*FLUX/INERT GAS WITH FLOW RATE*	ARGON 99.995% PURE 40 CFH MINIMUM

JOINT PREPARATION & SIDE NUMBER	SAW, CHIP OR GRIND, DEGREASE , WIRE BRUSH WITH STAINLESS STEEL POWER BRUSH IMMEDIATELY BEFORE WELDING FOR A DISTANCE OF AT LEAST ½" FROM WELD AREA.
INTERPASS CLEANING	REMOVE ALL OXIDES BEFORE WELDING NEXT BEAD, USE STAINLESS STEEL BRUSH
REPAIRS	REMOVE ALL DEFECTS BEFORE WELDING NEXT BEAD, CHIP OR GRIND
PREHEAT TEMPERATURE	NO REQUIREMENT

POSTHEAT TEMPERATURE	NO REQ.	*INTERPASS TEMPERATURE*	$100^{\circ}F$ MAX.
HEAT TREATMENT	NO REQUIREMENT	*ELECTRODE CONTROL*	TSCLA WELDING PROC. MAN. SEC. 3
WELD TECHNIQUE	ADJUST NOZZEL ANGLE AS NECESSARY TO MAINTAIN SHIELDING GAS COVERAGE.		

PASS NUMBER	*FILLER METAL SIZE*	*AMPERAGE RANGE*	*ARC VOLTAGE RANGE*	*POSITION*
ALL	3/64"	180-220	22-25	-

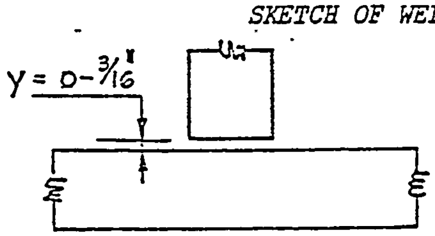
NOTES:

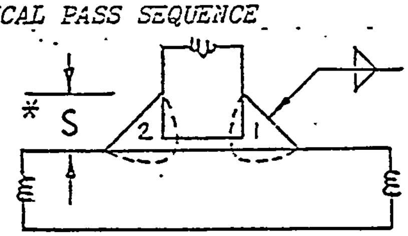
(1) Shield the area as necessary to maintain inert gas shield.

INSPECTION: IN ACCORDANCE WITH SEC. 6 OF TSCLA W. P. N-1.

JOINT DESIGN: PT2S.1 *SPEC.:* MILSTD22B *THICK. RANGE QUAL.:* UNLIMITED

SKETCH OF WELD JOINT DESIGN & TYPICAL PASS SEQUENCE





* WHERE Y EXCEEDS 1/16" INCREASE S BY AN AMOUNT EQUAL TO THE EXCESS ABOVE 1/16"

APPROVAL: TSCLA Weld. Engr. Dept.

EXHIBIT 16

TODD PACIFIC SHIPYARDS CORPORATION	PRODUCTION WELDING PROCEDURE	No: 568-3A
		Rev: 11/11/82 #51
		Issued 9/21/81 #47
LOS ANGELES DIVISION		Page 1 of 2

DESCRIPTION: V GROOVE BUTT JOINT WELDED ON PERMANENT BACKING STRIP, ALUMINUM ALLOY-TUBULAR

WELDER QUALIF.	MIL-STD-248	*PROCEDURE QUALIF. STD.*	MIL-STD-248 MIL-STD-278 NAVSHIPS 0900-000-1000 (1)
BASE METALS	QQ-A-250/20 Type 5456 W-T-700/5 Type 5086, Group S-25	*PROCESS*	Automatic Gas Metal Arc (Spray transfer) Welding - GMAW.
SPEC./TYPE FILLER METAL	MIL-E-16053 Type 5556 Group A-22B	*POWER SOURCE POLARITY*	Direct Current Electrode Positive
POSITION OF WELD	Flat & Horizontal Rolled	*FLUX/INERT GAS WITH FLOW RATE*	Helium, 100% pure & dry Grade A of BB-H-1168, 150-225 CFH
JOINT PREPARATION & SIDE NUMBER	Machine, plasma arc cut, chip, grind or deburr plate edges. Wire brush with a power stainless steel brush immediately prior to welding. Surfaces to be welded and adjacent surfaces within 1/2" from the expected toe of the weld shall be clean, dry and free of surface matter such as: paint, moisture, oxide film, oil, grease, indelible marking, etc.		
INTERPASS CLEANING	Remove all oxides before welding next bead. Use stainless steel power wire brush.		
REPAIRS	Remove all defects before welding next bead by chipping or grinding.		
PREHEAT TEMPERATURE	60° F minimum		
POSTHEAT TEMPERATURE	no requirement	*INTERPASS TEMPERATURE*	150° F maximum
HEAT TREATMENT	no requirement	*ELECTRODE CONTROL*	TPSLA Welding Proc. Manual N-1 Sec. 3
WELD TECHNIQUE	See notes below #2, #3 and following enclosure.		

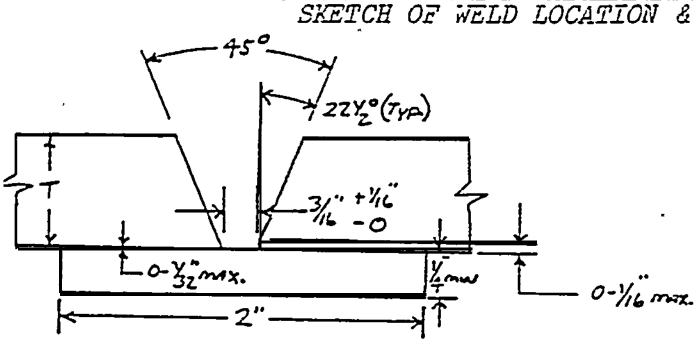
PASS NUMBER	*FILLER METAL SIZE*	*AMPERAGE RANGE*	*ARC VOLTAGE RANGE* 4	*POSITION*
All	1/16"	200-280	32-34	Flat

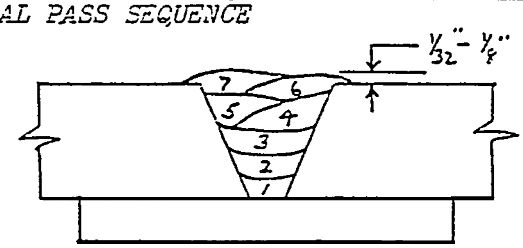
NOTES:

1. Gas cup size: 7/8" - 1"
2. Electrode lead angle 10° - 15°
3. Travel speed 22 -28 ipm.
4. Arc voltage range is at the meter, actual arc voltage is 32.

JOINT DESIGN: B1V.1 *SPEC.:* MIL-STD-22C *THICK. RANGE QUAL.:* 3/16" - 1"

SKETCH OF WELD LOCATION & TYPICAL PASS SEQUENCE





Number of passes shown are typical and shall be adjusted to suit each wall thickness.

APPROVAL: TSCLA Weld. Engr. Dept. John P. Maciel

Customer

EXHIBIT 17

TRI-MARK INC.
8585 INDUSTRY PARK DRIVE
PIQUA, OHIO 45356 513 773-2010

TRI-MARK® TM-711M Gas-Shielded Flux-Cored Wire

ALL-POSITION HIGH DEPOSITION ARC WELDING

AWS CLASS E71T-1

Code Data: AWS A5.20-79, ASME SFA 5.20, ABS Certificate No. 82-C26847-X, 3YSA

DESCRIPTION
TM-711M flux-cored welding wire is available in .045, .052 and 1/16 inch diameters for all-position semiautomatic arc welding of mild steel. The wire is especially designed for high quality welding with characteristics ideal for the welding operator. The arc is smooth and stable with quick freezing slag enhancing welding in vertical up, vertical down, and overhead positions. Flat and horizontal welds can also be readily accomplished. The wire is recommended for single and multiple pass welding. TM-711M meets the mechanical properties requirements of MIL-E-24403/1B.

OUTSTANDING CHARACTERISTICS
All-position welding, quick freezing slag, continuous welding, high deposition rates, high deposition efficiencies, smooth low-spatter arc, X-ray quality, excellent weld bead appearance, low cost deposits. Excellent impact values are higher than TM-711.

APPLICATION
TRI-MARK TM-711M electrode is designed to weld mild and medium carbon steels, such as A36, A285, A515 Grade 70, A516 Grade 70 and similar steels. A constant potential type welding machine is preferred, connected direct current reverse polarity, electrode positive. The arc may be shielded by either straight carbon dioxide gas or a mixture of 75% argon and 25% carbon dioxide.. Welding grade gas should have a dew point of minus 45°F or lower. Gas flow 35-50 c.f.h. TM-711M is packaged on 60-pound No. 2 coils, 25-pound B spools, 10-pound and 15-pound 8-inch spools.

Steel should be reasonably clean for best results. The smooth arc assists the welding operator in obtaining a sound weld with excellent bead appearance.

TYPICAL PROPERTIES determined by procedures outlined in AWS A5.20-79. All-weld-metal tension test specimen was aged as specified. Actual use of the product may produce varying results due to conditions and welding techniques over which Tri-Mark Inc. has no control. Any prior representations shall not be binding. *Tri-Mark Inc. disclaims any warranty of merchantability or fitness for any particular purpose with respect to its products.*

Consumers should be thoroughly familiar with the safety precautions shown on the Warning Label posted on each shipment and American National Standard Z49.1 "Safety in Welding and Cutting" published by the American Welding Society, 550 NW LeJeune Road, Miami, Florida 33135: OSHA Safety and Health Standards, 29 CFR 1910, available from the U.S. Department of Labor, Washington, DC 20210.

Typical TM-711M Mechanical Properties		CO_2 As-Welded	75A-25 CO_2 As-Welded
Ultimate Tensile Strength		88,000 psi	94,000 psi
Yield Strength		77,000 psi	86,000 psi
Elongation in 2 in.		26%	25%
Reduction of Area		65%	65%
Charpy V-Notch Impact.	0°F	54 ft.- lb.	54 ft.- lb.
	-20°F	40 ft.- lb.	43 ft.- lb.

Typical TM-711M Weld-Metal Composition	CO_2	75-25
Carbon	0.06	0.06
Manganese	1.35	1.53
Silicon	0.55	0.67
Phosphorus	0.005	0.005
Sulfur	0.011	0.011

TM-711M Welding Data

WELDING POSITION	WIRE DIA. in.	WIRE DIA. mm	AMPERAGE RANGE	VOLTAGE RANGE	OPTIMUM SETTINGS AMPERAGE	OPTIMUM SETTINGS ARC VOLTAGE	WIRE FEED SPEED in/min	WIRE FEED SPEED mm/s	DEPOSITED METAL lb/h	DEPOSITED METAL kg/h
Vertical Up	045	1.2	(100-200)	(22-27)	175-185	24-26	(130-250)240	(55-106)102	(3-6½)6	(1 4-2.9)2.7
Vertical Down	.052	1.3	(100-220)	(22-26)	175-200	23-25	(100-285)230	(42-121)97	(2½-6)5	(1.1-2.7)2.2
Overhead	1/16	1.6	(175-250)	(22-25)	200-220	23-25	(140-220)170	(59-93)72	(4½-8)6	(2.0-3 6)2.7
	For overhead try 1 volt higher than vertical.									
Flat and	.045	1.2	(100-300)	(22-31)	300	31	(130-500)500	(55-212)212	(3-10)10	(1.4-4 5)4 5
Horizontal	052	1.3	(100-300)	(22-29)	300	29	(100-420)417	(42-178)176	(2½-11)11	(1.1-5 0)5.0
	1/16	1.6	(150-400)	(22-33)	350	29	(150-425)350	(63-180)148	(4-15)13	(1 8-6 8)5.9

Electrode stickout, tip-to-work distance ¾". DCRP, Electrode positive.
For 75% argon - 25% carbon dioxide reduce all voltages 1 to 1½ volts.

Printed in U S.A. 8204711M-3

EXHIBIT 18

Gas Shielded Flux-Cored Wire Specification Sheet